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THE 1985 GLOBAL ICE IMPACT TESTS ON THE USCGC POLAR SEA

FINAL REPORT

Prepared for

**Transportation Development Centre
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Montreal, Quebec H2Z 1X4**

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MAY, 1987

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The contents of this report reflect the views of Arctec Canada Limited and not necessarily the official views or opinions of the Transportation Development Centre.

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17 Abstract

During September and October 1985, the POLAR SEA conducted ice impact tests on heavily ridged ice features in the Alaskan portion of the Beaufort Sea. Bending strain gauge measurements were used to estimate the longitudinal bending moment distribution of the POLAR SEA during an impact with an ice pressure ridge. Compressive strains along the stem and ship acceleration and velocity measurements were also recorded. This report describe the methodology for determining the global ice impact force, and presents the corresponding results of these tests. A comparison of the results with other available data is also presented. Hull strain, and impact force time histories are presented, along with the longitudinal bending and shear distributions, during ice impact events. The results indicate that the methodology used in estimating the impact force is valid and that full scale global load measurements provided an excellent understanding of ship/ice interaction.

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17. Résumé

En septembre et octobre 1985, une campagne de mesurage des efforts d'ensemble dus aux glaces a été menée à bord du brise-glace POLAR SEA dans la mer de Beaufort, au large de l'Alaska, caractérisée par un relief glaciel fortement accidenté. Des mesures extensométriques ont été prises pour calculer la valeur des déformations dues aux moments fléchissants et pour établir leur répartition longitudinale. Des extensomètres de compression fixés à l'étrave ont permis de mesurer les déformations de celle-ci et de connaître les valeurs d'accélération et de vélocité au moment des impacts. Ce rapport, qui rend compte de ces travaux, décrit une méthode pour déterminer les efforts d'ensemble dus aux glaces, dont il présente les résultats, et procède à la comparaison de ceux-ci avec ceux d'études antérieures. Il présente également les déformations de la coque avec la variation des forces d'impact dans le temps, ainsi que la répartition longitudinale des moments fléchissants et des efforts tranchants. Les résultats montrent que la méthode mise en oeuvre pour évaluer la force des impacts est valide et que son utilisation pour mesurer les efforts d'ensemble dus aux glaces apporte un éclairage intéressant sur l'interaction coque-glaces.

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SUMMARY

An instrumentation system was developed, using the experience gained from the 1983 Kigoriak and Robert Lemeur Impact Tests [15], and implemented for the measurement of global ice impact loads onboard the USCGC Polar Sea. From September 29, 1985 to October 12, 1985, the Polar Sea conducted ice-impact tests on heavily ridged ice features in the Alaskan portion of the Beaufort Sea. Bending strain gauge measurements were used to estimate the longitudinal bending moment distribution of the Polar Sea during an impact with an ice pressure ridge. Compressive strains along the stem, and ship acceleration and velocity measurements were also recorded. Hull strain, and impact force time histories were calculated, along with the longitudinal bending and shear distributions during ice impact events. The results indicated that the methodology used in estimating the impact force was valid. The full-scale global load measurements obtained can be used in the development and testing of ship-ice interaction models.

The overall objective of the project was to measure, record and analyse global ice-hull interaction stress in multi-year ice. This objective was further subdivided into the following goals:

1. Obtain a larger data base of ice loads for the development of analytical models describing ship-ice interaction.
2. Analyse the effect of ship displacement and bow shape on global ice loads by comparison of the Polar Sea loads with other available data.

The following main conclusions were made from this work:

1. The use of bending gauges provided an excellent estimate of the longitudinal shear and bending moment distributions.
2. The stem bar compression gauges provided an estimate of the impact velocity of the Polar Sea, as well as the centre of location of the ice force.
3. The ice force on the Polar Sea should not be treated as a point load.
4. The maximum measured bending stress of 41.9 MPa was recorded from the gauges on the 01 deck at the forward end of the superstructure (Frame 39).
5. The loading rate was measured to be as high as 50 MN/sec, compared to the Kigoriak's loading rate of 150 MN/sec [13].
6. The impact duration (length of time of first peak) is approximately 0.8 seconds for the Polar Sea. This compares with 0.48 seconds for the Kigoriak.
7. The dominant response of the vessel was at the first mode of vibration (3 Hz).
8. The maximum calculated vertical bow force during ramming was 24.97 MN.

It is recommended that:

1. Further analysis be done on the unsymmetric ramming tests (e.g., estimate of the transverse force).
2. Parametric study on the bow shape (flare angle, stem angle, etc.) on the effectiveness on navigation of icebreakers through ridges be conducted.
3. Further analysis of the stem bar gauges be conducted (e.g., ice contact length vs. time, distribution of stresses along the stem bar).

SOMMAIRE

Tirant parti de l'expérience acquise en 1983 à bord du KIGORIAK et du ROBERT-LEMEUR, une chaîne de mesure a été réalisée et installée à bord du brise-glace américain POLAR SEA aux fins du mesurage des efforts d'ensemble dus aux glaces. Entre le 29 septembre et le 12 octobre 1985, une campagne de mesurage a été menée dans la mer de Beaufort au large de l'Alaska, caractérisée par un relief glaciel fortement accidenté. Des mesures extensométriques ont été prises pour calculer la valeur des déformations dues aux moments fléchissants et pour établir leur répartition longitudinale. La déformation de l'étrave a été mesurée ainsi que l'accélération et la vitesse du navire. Enfin, les déformations de la coque ont été calculées, avec les variations des forces d'impact dans le temps, permettant d'établir la répartition longitudinale des moments fléchissants et des efforts tranchants. Les résultats montrent que la méthode mise en oeuvre pour évaluer la force des impacts est valide et que son utilisation pour mesurer les efforts d'ensemble dus aux glaces apporte un éclairage intéressant sur l'interaction coque-glaces.

La recherche avait pour objet de mesurer, enregistrer et analyser les efforts d'ensemble suscités par la collision de la coque avec des glaces de plusieurs années. Les sous-objectifs spécifiques ont été les suivants:

1. Enrichir la base de données sur les charges des glaces dans la perspective d'une modélisation de l'interaction coque-glaces.

2. Étudier l'effet du déplacement du navire et de la forme de la proue sur les efforts d'ensemble, en comparant les résultats obtenus du POLAR SEA avec ceux d'études antérieures.

La recherche a débouché sur les grandes conclusions suivantes:

1. Les capteurs de flexion ont permis une très bonne estimation de la répartition longitudinale des moments fléchissants et des efforts tranchants.

2. Les extensomètres d'étrave ont permis de localiser le centre des efforts et d'estimer la vélocité du navire au moment des impacts.

3. La charge des glaces ne doit pas être considérée comme un effort localisé.

4. La contrainte de flexion maximale de 41,9 MPa a été enregistrée par les extensomètres sur le pont 01 à l'extrémité avant de la superstructure (cadre 39).

5. Le taux de charge maximal a été de 50 MN/s, comparativement aux 150 MN/s dans le cas du KIGORIAK.

6. La durée d'impact (durée de la première crête) a été de 0,8 s

environ, comparativement à 0,48 s dans le cas du KIGORIAK.

7. La réponse vibratoire dominante de la coque a été en mode fondamental (3 Hz).

8. L'effort vertical maximal à la proue en marche alternée a été de 24,97 MN.

Les recommandations formulées sont les suivantes:

1. Approfondir l'analyse des forces transversales par des marches alternées asymétriques.

2. Établir la relation entre vélocité et effort en marches alternées dans des conditions glacielles identiques.

3. Poursuivre l'analyse des données extensométriques à l'étrave: longueur du contact en fonction de la durée, répartition des contraintes le long de l'étrave.

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1. INTRODUCTION

The Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR) [1] were developed in 1972. Since that time a number of analytical models describing ship-ice interaction have been developed using rigid body idealization, flexible beam elements, and three dimensional finite element models, [2,3,4,5,]. Full-scale impact tests have been conducted on the following icebreaking vessels: M.V. Canmar Kigoriak, M.V. Robert Lemeur, M.V. Arctic, and now the USCGC Polar Sea [6,7,8,9,10,11]. Physical modelling of the ship-ice impact process for the M.V. Arctic has also been carried out by Arctec Canada Limited for the Canadian Coast Guard [12] and also by the Technical Research Centre of Finland under a joint research program between Canada and Finland. The focus of this work in Canada has been to provide a sound technical basis for further development of the CASPPR, to accommodate the technical and regulatory requirements of expanding maritime operations in the Canadian Arctic.

The term "global ice load" is defined as the net resultant of the ice loads generated at the many local contact areas around the bow of a ship during an impact with a large ice feature. These global ice loads may generate significant bending moments in the hull girder, which may affect the structural integrity of icebreaking ships. This in turn may have implications on the design of the icebreaking vessels and specifically may require additional design criteria for the strength of the hull girder. The purpose of the present work was to measure full-scale global loads on a vessel to assist in understanding the significance of the loading.

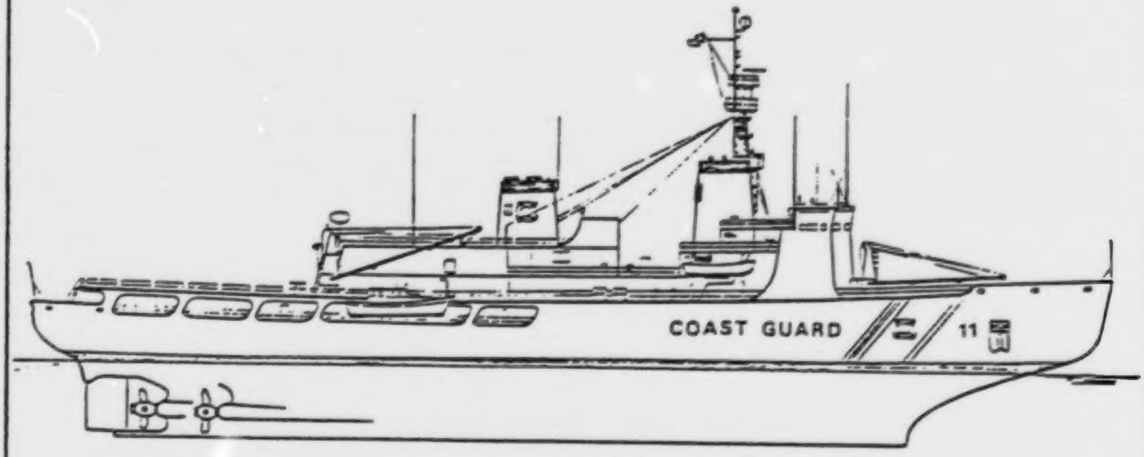
This report describes the results of full-scale global load measurements on board USCGC Polar Sea sponsored jointly by: the U.S. Maritime Administration, the Canadian Ministry of Transport, the U.S. Interdepartmental Ship Structures Committee, the U.S. and Canadian Coast Guards, and the American Bureau of Shipping, Newport News Shipbuilding, Bethlehem Steel and the following A.O.G.A companies: Arco, Chevron, Exxon, Mobil, and Shell. A full description of the instrumentation, the data acquisition system and the analysis methodology is included.

The work presented here was carried out onboard the USCGC Polar Sea in the Alaskan Beaufort Sea between September 19, 1985 and October 13, 1985. The principal particulars of the vessel are shown in Figure 1.

The overall objective of the project is to measure, record and analyse global ice-hull interaction stress in multi-year ice. This objective was further subdivided into the following goals:

1. Obtain a larger data base of ice loads for the development of analytical models describing ship-ice interaction.
2. Analyse the effect of ship displacement and bow shape on global ice loads by comparison of the Polar Sea loads with other available data.

The work reported herein fulfills a portion of the research contract placed on Arctec Canada Limited by the Transportation Development Centre under Contract No. 11SD.T8700-5-5531. Other portions of this contract pertaining to local load measurement, and an Antarctic deployment are reported separately. Appendix A presents the Statement of Work with the references to the location in the report where the specified work is addressed.



SHIP STATISTICS:

LENGTH OVERALL	399 FEET	(121.6 m)
LENGTH AT WATERLINE	352 FEET	(107.3 m)
BEAM	83.5 FEET	(25.3 m)
DRAFT	31.8 FEET	(9.7 m)
DISPLACEMENT, CAPACITY LOAD	13,190 TONS	(117.4 MN)
RANGE (MAXIMUM)	28,274 MILES	(42,240 km)
SUSTAINED SPEED (OPEN WATER)	17 KNOTS	(8.75 m/s)
PROPULSION	DIESEL ELECTRIC OR GAS TURBINE	
SHP	18,000 D-E 60,000 G-T	(13.4 MW) (44.8 MW)
NUMBER OF SCREWS	3	
COMPLEMENT	14 OFFICERS 126 ENLISTED	
SCIENTIST ACCOMMODATIONS	20	
HEIGHT OF BRIDGE ABOVE WATERLINE	55 FEET	(16.8 m)
HEIGHT OF ALOFT CONN ABOVE WATERLINE	104 FEET	(31.7 m)

FIGURE 1

PRINCIPAL FEATURES OF A POLAR CLASS ICEBREAKER

2. INSTRUMENTATION AND DATA ACQUISITION SYSTEM

2.1 Introduction

The instrumentation system developed for this project is illustrated in Figure 2. This system was developed from the one used by Canadian Marine Drilling Ltd. (Canmar) in the 1983 M.V. Kigoriak and M.V. Robert Lemeur Full-scale Impact Tests (7). There are two fundamental differences in these systems. This system measured the longitudinal bending strain distribution spanning the location of the ice load, whereas the Canmar system measured the shear strain sections near the location of the ice load and bending strain distribution aft of the location of the ice force. Secondly, in these tests the actual longitudinal location of the load was measured while in the earlier work this had to be inferred from other data. The following are the advantages obtained by improving the Canmar system:

1. Bending measurements require fewer gauges. This allowed more Frames to be instrumented for the same number of gauges and cost.
2. An excellent definition of the longitudinal shear distribution, spanning the location of the load, can be obtained because of the larger number of instrumented Frames.
3. The location of the centre of the load is measured directly.

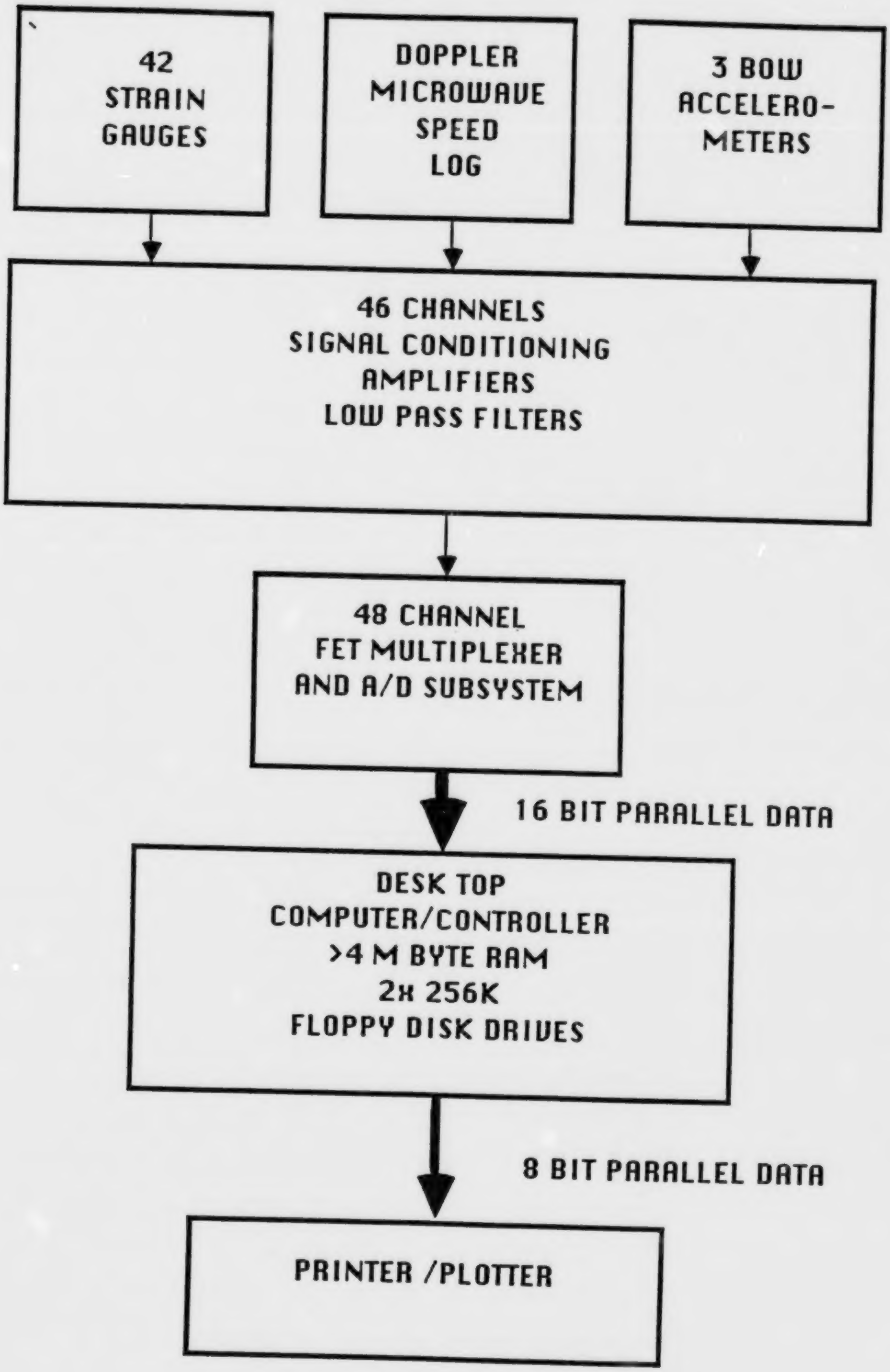

42 STRAIN GAUGES
DOPPLER MICROWAVE SPEED LOG
3 BOW ACCELERO-METERS
46 CHANNELS SIGNAL CONDITIONING AMPLIFIERS LOW PASS FILTERS
48 CHANNEL FET MULTIPLEXER AND A/D SUBSYSTEM
16 BIT PARALLEL DATA
DESK TOP COMPUTER/CONTROLLER >4 M BYTE RAM 2x 256K FLOPPY DISK DRIVES
8 BIT PARALLEL DATA
PRINTER /PLOTTER

FIGURE 2:
Impact Data Acquisition System

2.2 Location of Strain Gauges

To estimate the vertical ice force on the bow, during an impact with a heavy ice feature, the shear around the location of the ice force must be well defined. As shown in Figure 3, the shear force changes abruptly over a relatively short distance around the location of the load. The bending moment diagram must therefore be well defined in this area to obtain precise determination of the shear force (negative slope of the bending moment diagram). Therefore, the majority of the stations instrumented for bending were located near the anticipated location of the ice force. The location of the bending gauges are shown in Figure 4.

Bending gauges were placed on the 01 deck parallel to the side shell, on both port and starboard sides. This enabled the exclusion of torsional strain (by averaging the strains on port and starboard) in the calculation of the longitudinal bending strain due to the vertical ice force. This also allowed for the determination of symmetrical rams (loads). Forward of Frame 86 bending gauges were also located on lower levels, which permitted elimination of the longitudinal force in the calculation of the bending moment.

Compression gauges for estimating the location of the load were installed along the keel contact zone. They were placed on the centre line web longitudinal, 12 to 16 inches above and perpendicular to the stem bar, and 1.5 inches forward of the cant Frames, as shown in Figure 5. The spacing of these gauges enabled an accurate estimation of the location of the ice force on the centre line to be made (+/-0.47 m (+/-18 inch)). This system also provided an estimate of impact speed.

Transverse compression gauges were installed on cant Frame 35 near the keel as shown in Figure 6. The output from these gauges can be used in estimating the width of the contact area and the distribution of stress across the bow of the Polar Sea.

All the strain gauges were uniaxial, wired as opposite-active arm bridges and had an excitation of 10 volts.

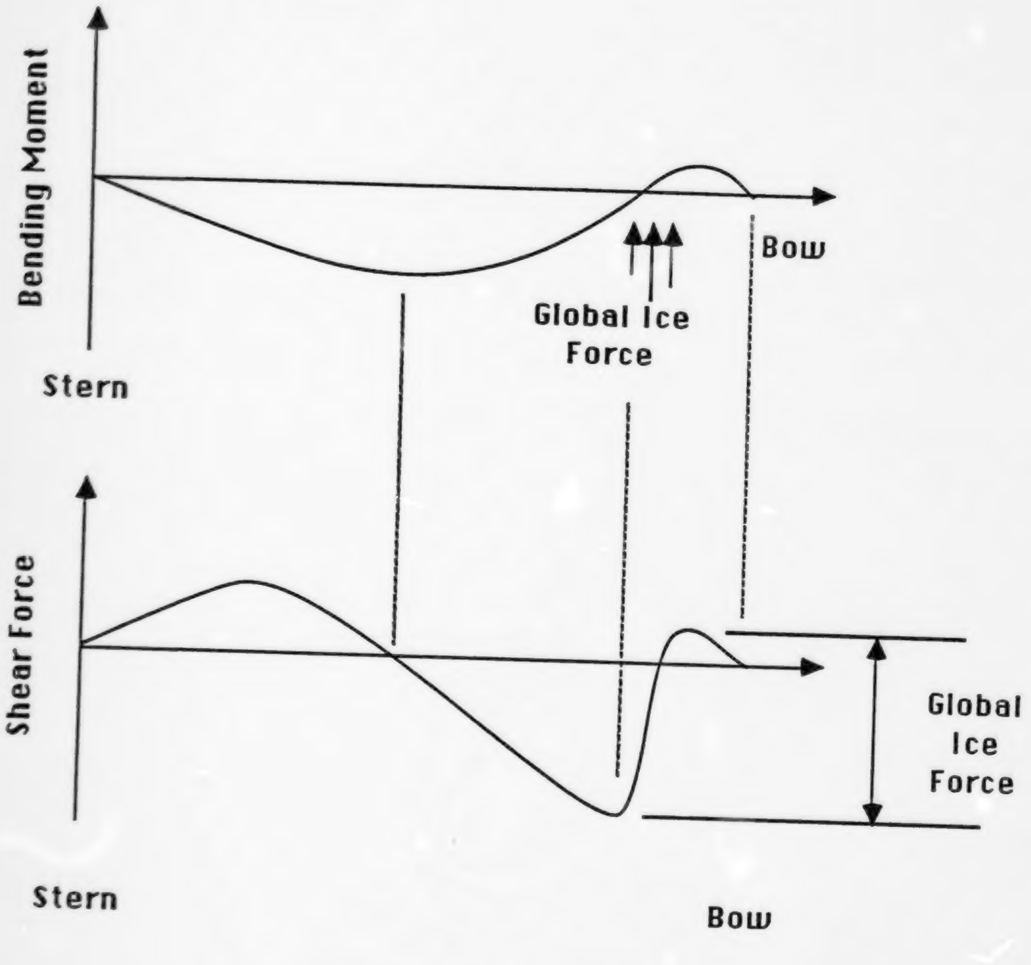

Bending Moment
Bow
Global Ice
Force
Stern
Shear Force
Global
Ice
Force
Stern
Bow

Figure 3
Estimated Shear and Bending
Moment Diagrams for the
USCGC "Polar Sea"

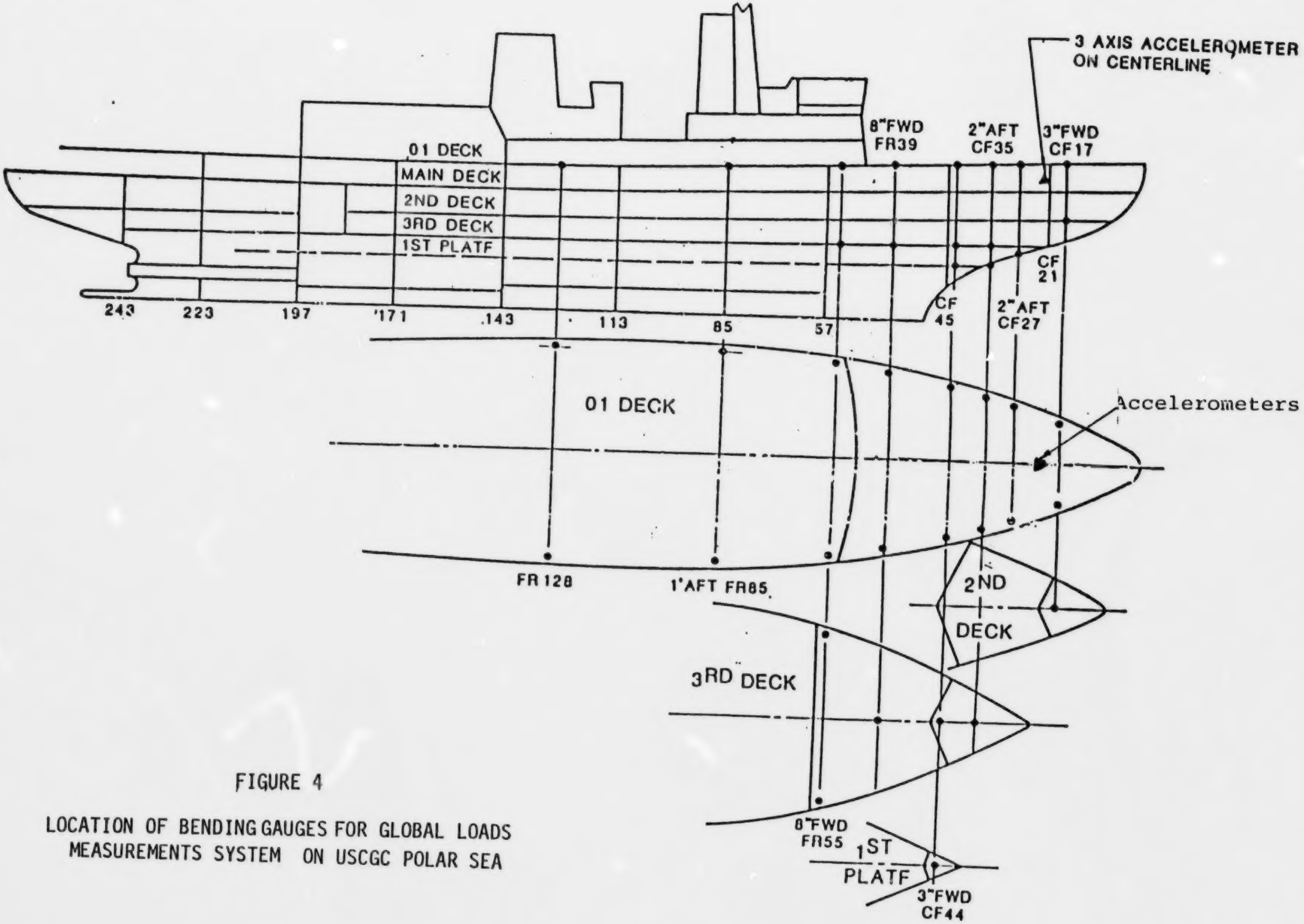

3 AXIS ACCELEROMETER ON CENTERLINE
01 DECK
MAIN DECK
2ND DECK
3RD DECK
1ST PLATF
8"FWD FR39
2"AFT CF35
3"FWD CF17
CF 21
CF 45
2"AFT CF27
243
223
197
171
143
113
85
57
01 DECK
Accelerometers
FR 128
1'AFT FR85
2ND DECK
3RD DECK
8"FWD FR55
1ST PLATF
3"FWD CF44

FIGURE 4

LOCATION OF BENDING GAUGES FOR GLOBAL LOADS MEASUREMENTS SYSTEM ON USCGC POLAR SEA

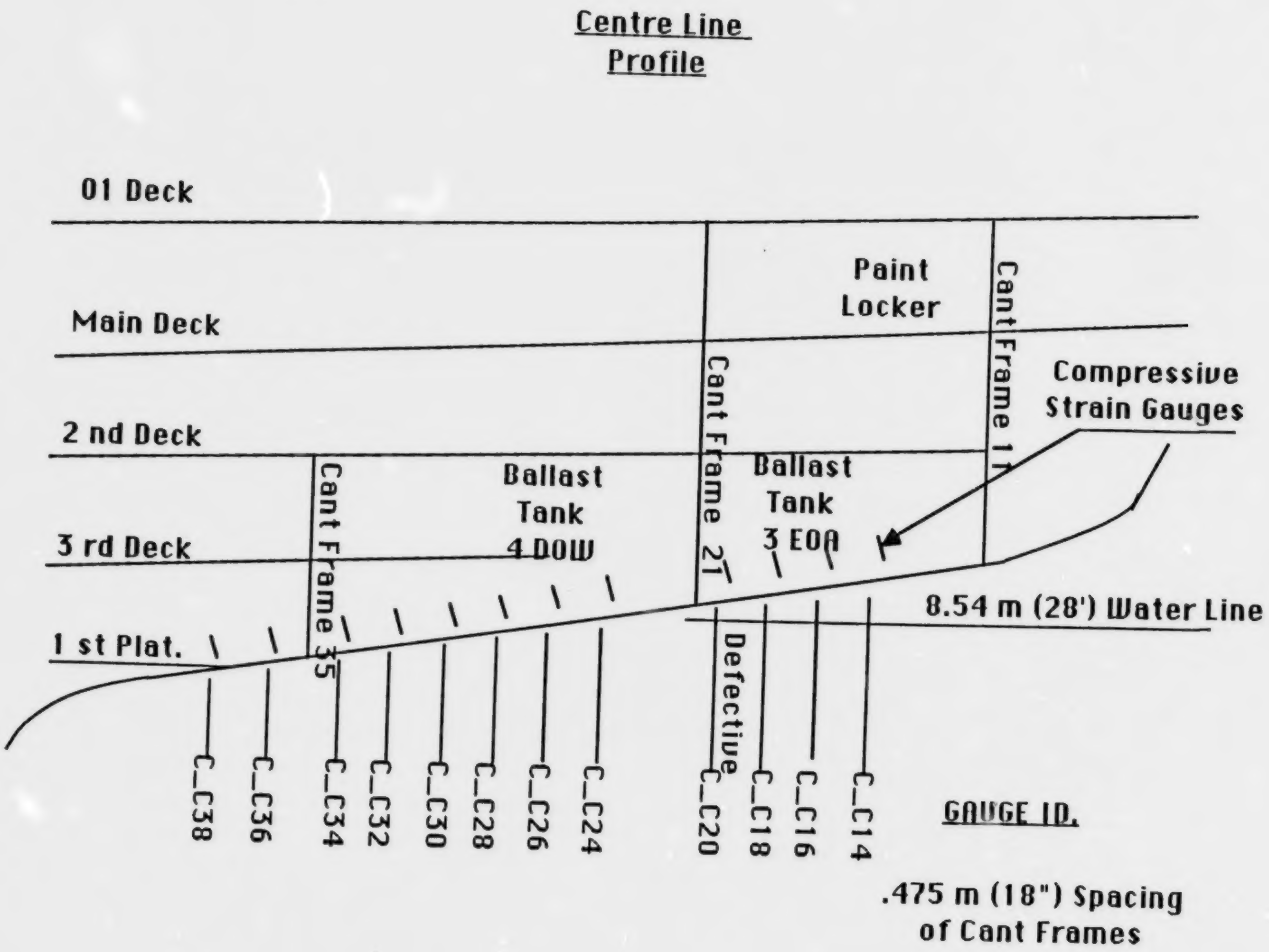
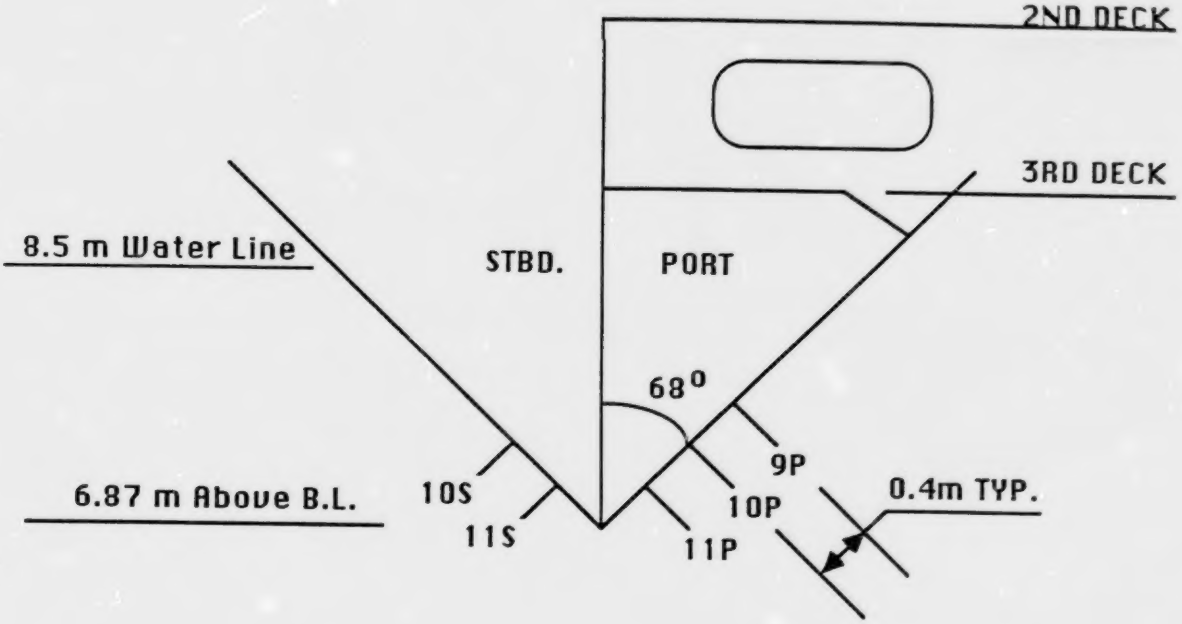

Centre Line Profile
01 Deck
Main Deck
2 nd Deck
3 rd Deck
1 st Plat.
Paint Locker
Cant Frame 11
Cant Frame 21
Cant Frame 35
Compressive Strain Gauges
Ballast Tank 3 EOA
Ballast Tank 4 DOW
8.54 m (28') Water Line
Defective
C_C38
C_C36
C_C34
C_C32
C_C30
C_C28
C_C26
C_C24
C_C20
C_C18
C_C16
C_C14
GAUGE ID.
.475 m (18") Spacing of Cant Frames

Figure 5:
Location of Compression Gauges
on Centre Line Web Frame


2ND DECK
3RD DECK
8.5 m Water Line
STBD.
PORT
68°
9P
10S
10P
0.4m TYP.
6.87 m Above B.L.
11S
11P

LOCATION	CHANNEL ID.
10S	C_C35_10S
11S	C_C34_11S
11P	C_C35_11P
10P	C_C35_10P
9P	C_C35_9P

Figure 6:
Location of Transverse Compression Gauges on Cant Frame 35

2.3 Description of Transducers

The specifications and locations of all the transducers used for the onboard instrumentation are tabulated in Appendix B. All the strain gauges were wired as opposite-active arm bridges and had an excitation of 10 volts. The resulting calibration was 49.75 micro-strain per volt for all rams except Ram 1 and Ram 2, which had a calibration of 497.5 micro-strain per volt for channel 2 to channel 26.

Three uniaxial accelerometers were located in the bow area as shown in Figure 4. These comprised of one triaxial array oriented to the ship's principal axes. The outputs from these accelerometers were used to determine if its ram was symmetric. They could also be used in future analysis for the following:

1. Provide an estimate of the inertial forces forward of the ice force.
2. Help assess the relative importance of the longitudinal, transverse and vertical ice forces acting on the vessel.

The vessel was also equipped with a doppler microwave speed log. This provided an estimate of the impact velocity.

2.4 Channel Bandwidth Requirements

The required channel bandwidth for measurement of the strain response of the Polar Sea is dependent on its rate of loading and its vibrational frequency. Previous experiments indicated that the dominant vibrational frequency was approximately 3 Hz. The rate of loading was estimated by the predicted rise time of the ice force. Previous measurements and model tests indicated the rise time to be as low as .1 seconds. This corresponds to a frequency of 2.5 Hz, for a quarter sine rising load shape. The minimum analog bandwidth was estimated to be approximately 5 Hz to reproduce the relevant information in the data. For accurate amplitude reproduction of transient signals, approximately 10 to 20 digital samples per cycle of the highest analog frequency in the data are required. The accuracy estimating the peak amplitude using 10 samples per cycle is +/- 2.5% and for 20 samples per cycle is +/- 0.6%. Therefore, the sampling rate was set at 100 samples per second.

2.5 Signal to Noise Requirements

Expected maximum peak strains of approximately 500 micro strain for high loads and approximately 50 micro strain for low loads, were predicted from previous experiments. To accurately measure these bending strains, the resolution of dynamic strains in the order of one to two micro strain was required. In order to minimize noise, proper grounding and shielding practices, based on previous experience, were applied. Low pass filters were also used on the outputs, with a corner frequency set at 10 Hz. From the signal conditioning the data was sent as +/- 10 volt outputs directly to a FET switching multiplexer and an analog-to-digital subsystem having 12 bit resolution. This resolution corresponded to .25 microstrain for all the strain gauges, .012 knots for the speed log, .0012 g's and .0006 g's for the vertical and horizontal accelerometers respectively.

2.6 Data Control and Storage

The control, storage and processing of the data was performed by the Hewlett Packard series 200 model 9816 desk top computer. The processor in this machine is the Motorola 68000. The internal memory was approximately 4.3 Mbytes. The 9816 was used to program the a/d subsystem (HP 6940B Multiprogrammer). The data was stored on 3.5 inch floppy disks, one ram for each disc (48 channels sampled at 100 readings/sec/channel for 25 seconds). Extra components were available in case the failure of one or more components occurred.

2.7 Equipment Installation/Status

The installation of electronic equipment and strain gauges onboard the Polar Sea was carried out in July 1985, approximately two months before the tests were conducted.

During the commissioning of the data acquisition system all the electronic equipment was found to be intact and in proper operating condition. When this was done it was found that three of the strain gauge bridges located on the 01 weather deck, and one bridge in the EOW forward water ballast tank, were not functioning properly due to exposure to salt water.

The strain defective strain gauge bridges on the 01 weather deck were replaced with new gauges. The defective bridge in the EOW tank (one of the centre-line compression bridges used to locate the load along the stem bar) was frozen beneath two feet of ice in the lowest part of the tank. Because it was judged that ample load locating capability was provided by the rest of the centre-line array, it was decided not to attempt to replace it.

When connected to the data acquisition gauges system, the refurbished gauge array was found to provide clean, noise free data. Worst case noise was observed to be less than 20 millivolts in a +/- 10 volt range. A total of 41 strain gauge signals were recorded during the tests. All channels were sampled at 100 readings per channel per second.

3. DESCRIPTION OF THE TEST PROGRAM

3.1 Summary of the Test Program

During the first leg of the global loads test program (September 29, 1985 to October 4, 1985), a total of eight rams against thin ice for system checkout were executed. Eleven ramming tests were conducted on the first leg and twenty-nine ramming tests were achieved during the second leg (October 5, 1985 to October 13, 1985) of the test program, for a total of forty rams. The impact velocities were from four to twelve knots against multi-year ridges and ridge fragments. The number of rams performed was limited by the amount of suitable ice features that could withstand multiple rams. Ice conditions suitable for ramming tests required more time to find than in a normal season, because of the lack of heavy ice features near Barrow, Alaska. All the ridges were broken on the first impact with the exception of three rams (Ram 31, Ram 37, Ram 38). Table 1 lists the important observations and comments recorded for each ramming test.

3.2 Test Procedure

Suitable ice features for conducting ramming tests were located by helicopter reconnaissance. The ice feature (a floe containing multi-year ridges) was marked and the ship directed towards the floe and inside it. Arctec personnel, as well as the participant's representatives, then collected environmental and ice data using the following systems:

1. A remotely operated underwater vehicle (ROV), carrying upward-looking sonar and a low light level TV camera, for wide area sub-surface profiling of the ice features to be rammed.
2. Mesotech scanning sonar, deployed through a borehole in the ice, for local sub-surface ice profiling.
3. Thermal ice drill, using hot water flow, for rapid sounding of the ice from the surface.
4. Electronic distance meter, incorporated in a surveyor's "Total Station" and with electronic data logging, for surveying the top surface topography of the ice features.

A summary of the environmental data collection is listed in Table 2. The results from the environmental data collection are reported separately.

TABLE 1
Observations of Ramming Tests

Date	Ram No.	Symm- etric	Hard	First Ram	Ridge Broken	Location	Comments
85/10/02	1	Y	Y	Y	Y	Site 1	
85/10/02	2	Y	Y	Y	Y	Site 2	Good Hit
85/10/04	3	Y	Y	Y	Y	Site 3	12 m Ridge
85/10/04	4	Y	Y	Y	Y	Site 3	
85/10/04	5	Port	Y	Y	Y	Site 4	Good Heave
85/10/04	6	Port	N	Y	Y	Site 4	Roll & Pitch
85/10/04	7	Y	N	Y	Y	Small Floe	Good Acc. ch
85/10/04	8	Y	N	Y	Y	Small Floe	Floe Submerged
85/10/04	9	Y	N	Y	Y		
85/10/04	10	Y	N	Y	Y	Small Floe	
85/10/04	11	Y	N	Y	Y	Small Floe	
85/10/04	12						Not Recorded
85/10/06	13						
85/10/07	14	Y	N	Y	Y	Site 5	Beaching Force
85/10/07	15	Y	N	Y	Y	Site 5	
85/10/07	16	Y	Y	Y	Y	Site 5	2nd Hit Hard
85/10/08	17	Y	Y	Y	Y	Site 6	3 Hits
85/10/08	18	Y	Y	Y	Y	Site 6	Hit Ice Knife
85/10/08	19	Stbd.	N	Y	Y	Site 6	Bounced to Port
85/10/08	20	Y	N	Y	Y	Small Floe	
85/10/08	21	Y	Y	Y	Y	Small Ridge	
85/10/08	22	Y	Y	Y	Y	Small Ridge	
85/10/10	23	Y	Y	Y	Y	Cent. Site 7	3 Hinge Break
85/10/10	24	Y	Y	Y	Y	Right Site 7	Floe Submerged
85/10/10	25	Y	Y*	Y	Y	Left Site 7	Floe Submerged
85/10/10	26	Y	Y*	Y	Y	Right Site 7	Floe Submerged
85/10/11	27	Y	N	Y	Y	In Transit	Small Ridge
85/10/11	28	Y	N	Y	Y	In Transit	Small Ridge
85/10/11	29	Y	N	Y	Y	In Transit	Small Ridge
85/10/11	30	Y	N	Y	Y	In Transit	Small Ridge
85/10/11	31	Y	Med	Y	N	In Transit	Small Ridge
85/10/11	32	Stbd.	Med	Y	Y	In Transit-A	Glanced to Port
85/10/11	33	Y	Med	Y	Y	In Transit-A	Large Heave
85/10/11	34	Y	Y*	Y	Y	In Transit-A	Good Hit
85/10/11	35	Y	Med	Y	Y	In Transit-A	
85/10/11	36	Y	N	Y	Y	In Transit-A	Light Hit
85/10/12	37	Y	N	Y	N	In Transit-B	Beaching Force
85/10/12	38	Y	N	2	N	In Transit-B	Impact on Bow Print
85/10/12	38	Y	Y*	3	Y	In Transit-B	Good Impact
85/10/12	40	Port	Y	Y	Y	In Transit-B	Hit Port Side

Y* Indicates one of the hardest impacts
In Transit-B Indicates a location B in Transit
In Transit-A Indicates a location A in Transit

TABLE 2
SUMMARY OF ENVIRONMENTAL DATA COLLECTION PROGRAM POLAR SEA DEPLOYMENT IN THE BEAUFORT SEA - FALL 1985

LEG 2A : SEPTEMBER 29 - OCTOBER 5, 1985

SITE 1:
30 September - 1 October
13 ft Sail, 23 ft Keel
No Ice Strength Measurements
-9° C Average Air Temperature

SITE 2:
2 October
11 ft Sail, 20 ft. Keel
3.16 MPa (458 psi) Average Crushing Strength
0.57 MPa (82.8 psi) Average Flexural Strength
-6° C Average Air Temperature

SITE 3:
3 October
13 ft Sail, 25 ft Keel
3.30 MPa (479 psi) Average Crushing Strength
0.61 MPa (88.9 psi) Average Flexural Strength
-4° C Average Air Temperature

SITE 4:
4 October
14.5 ft Sail, 48 ft Keel
2.82 MPa (410 psi) Average Crushing Strength
0.54 MPa (79 psi) Average Flexural Strength
-3° C Average Air Temperature

LEG 2B : OCTOBER 5 - OCTOBER 13, 1985

SITE 5:
6 October - 7 October
10.8 ft Sail, 31 ft Keel
3.43 MPa (498 psi) Average Crushing Strength
0.63 MPa (92 psi) Average Flexural Strength
-2° C Average Air Temperature

SITE 6:
8 October
18.5 ft Sail, 47 ft Keel
4.22 MPa (612 psi) Average Crushing Strength
0.14 MPa (108 psi) Average Flexural Strength
-16° C Average Air Temperature

SITE 7:
9 October - October 10
16.5 ft Sail, 48 ft Keel
4.38 MPa (635 psi) Average Crushing Strength
0.76 MPa (111 psi) Average Flexural Strength
-22° C Average Air Temperature

Note: Report by Arctec Engineering entitled "Environmental Data Collection Aboard USCGC Polar Sea 1985, Volume I: Environmental Data" contains more details but is confidential until March 1990 [21].

Following the on ice data collection effort, the vessel proceeded to conduct ramming tests on the profiled ice features. A typical ramming test consisted of the following sequence of events:

1. The icebreaker cleared a path to ram the ice feature.
2. The vessel was moved perpendicular to the ridge feature and several ship lengths away.
3. Ahead power was applied and the vessel was directed towards the ridge.
4. Approximately five seconds prior to impact, the data acquisition was started and data acquired for 25 seconds. The time of impact was estimated from a video screen displaying the bow of the vessel and the immediate area ahead, located at the data acquisition centre.
5. The data was converted from binary to integer format and then stored on a floppy disc (approximately 60 seconds).
6. The data was then analysed and plotted.

The log of the ramming tests is given in Appendix C.

4. DATA ANALYSIS

4.1 Analysis Procedures and Results

Analysis software was developed before deployment and refined during and after the tests. This software was used to conduct the following analyses on the data obtained in the impact test program. The listing of the software and documentation is provided in Appendix D.

4.1.1 Deck Bending Stress

The deck bending stress time history at each location was calculated and plotted for every ram. These stresses were calculated by multiplying the strain above a baseline value, established just prior to impact, by the elastic modulus and a calibration factor. The gauges placed parallel to the side shell required a correction to determine the strain parallel to the centre line. A base line was subtracted from each reading to obtain the change in strain due to the ice load.

A time history plot of the maximum bending stress measured during the test is shown in Figure 7. During the ramming tests the maximum bending stress was determined within a minute of completion of the ram. These values were compared with the yield stress of the deck (approximately 310 MPa [45,000 Psi] to determine if any damage had occurred. A histogram of the maximum bending stress is shown in Figure 8. Figure 9 illustrates the first mode vibrational frequency of the Polar Sea, measured by a starboard bending gauge located at Frame 128 (near midships) on the 01 deck. The measured frequency of 3.0 Hz is within 8% of a previously measured value of 2.75 Hz [2], and a frequency of approximately 2.9 Hz estimated from a finite element model constructed by A.B.S.

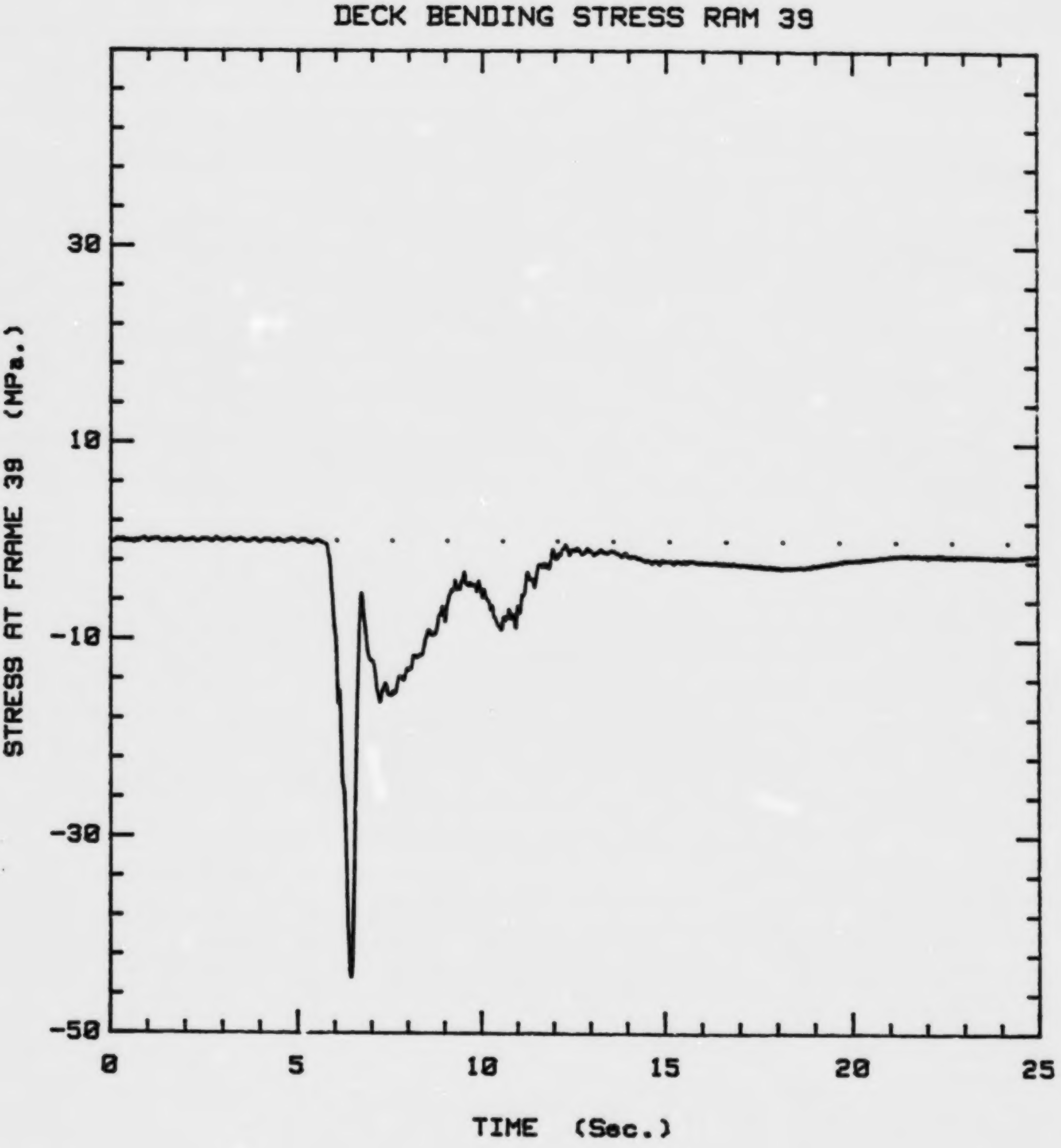


Figure 7 Bending Stress Time History at Frame 39

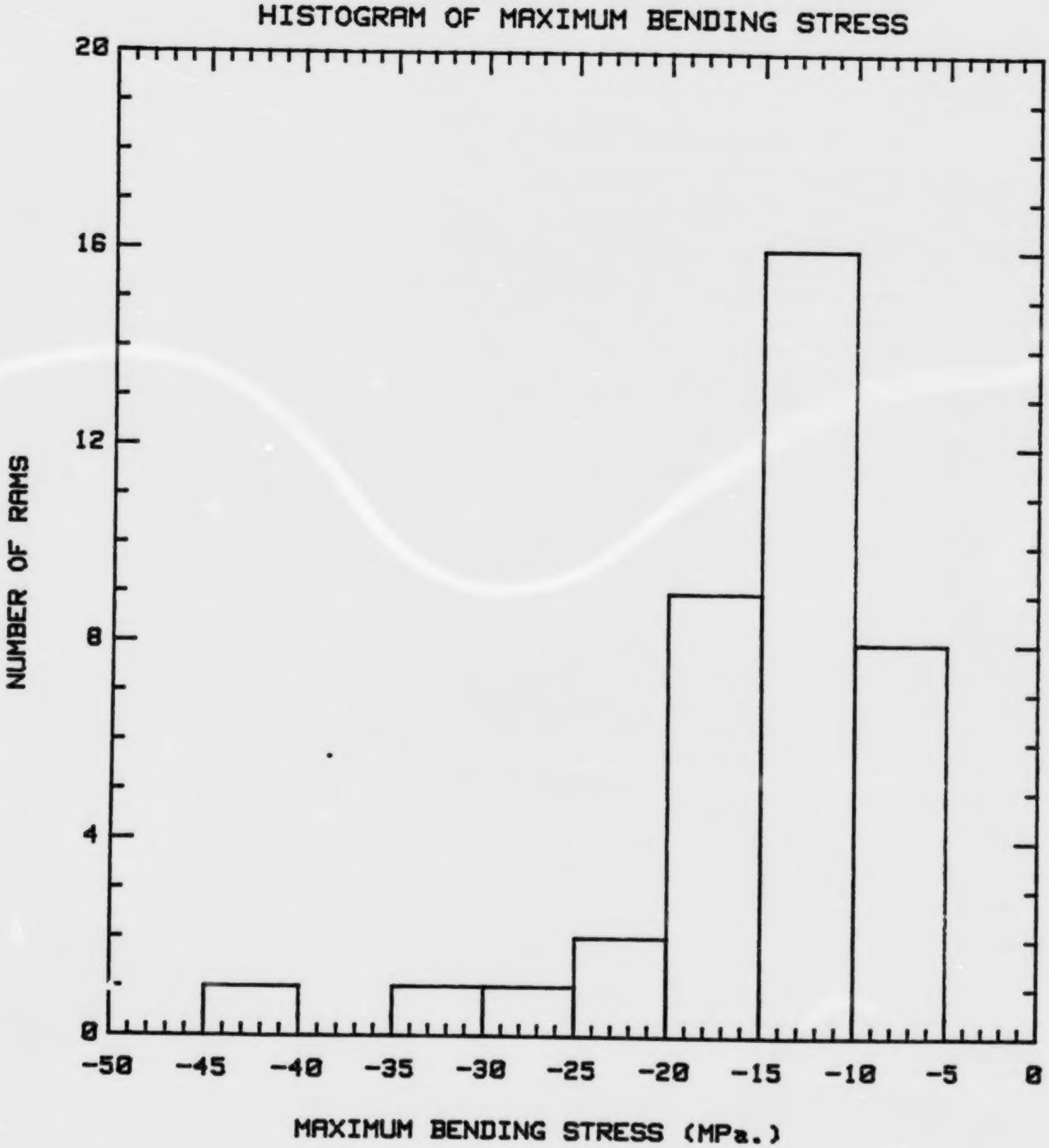


Figure 8 Histogram of Maximum Bending Stress

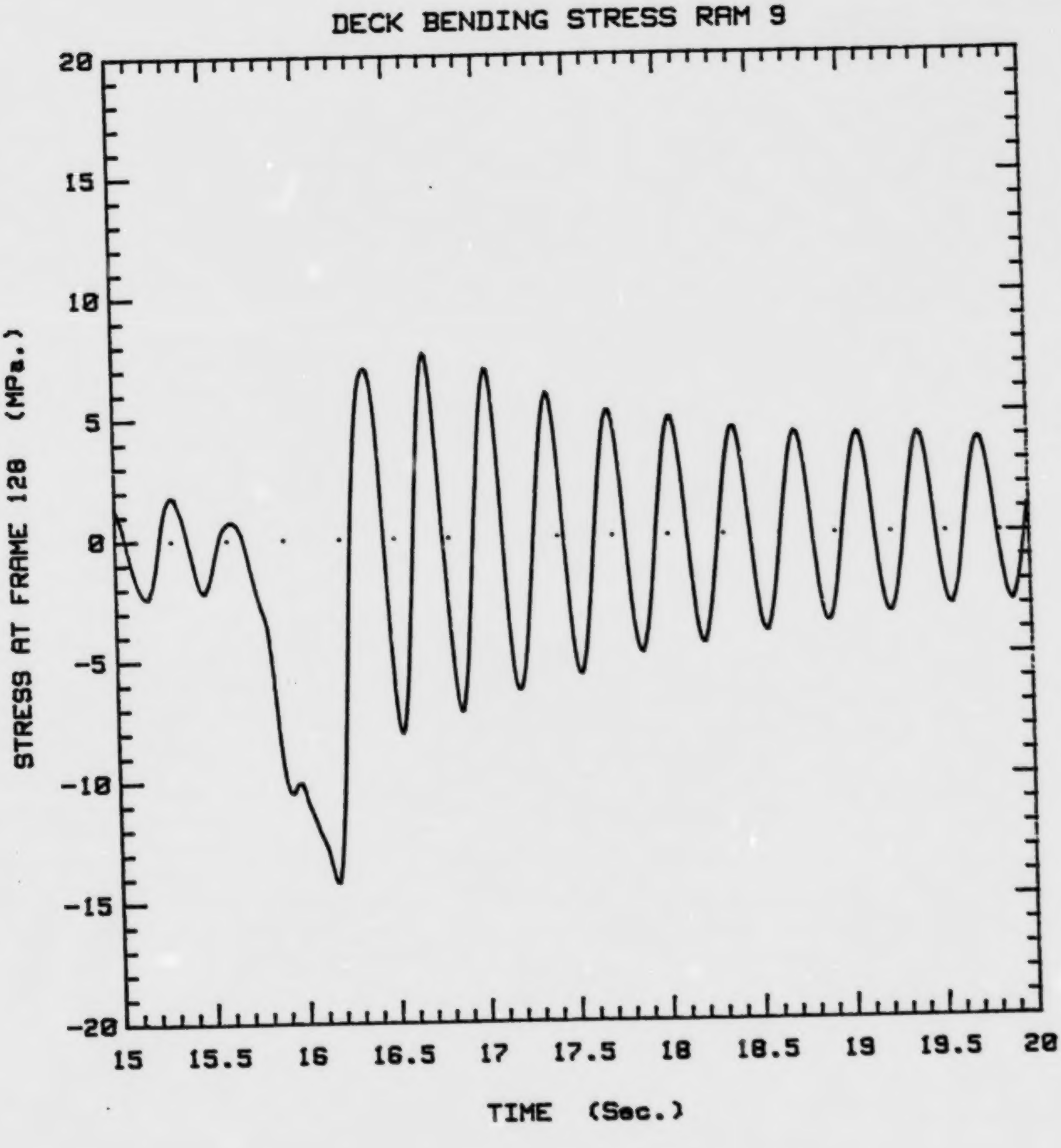


Figure 9 Bending Stress Time History at Frame 128

4.1.2 Vertical Ice Force

The vertical component of the ice force on the bow was calculated every 0.01 seconds for the 25 seconds of data recorded during each ramming test. This was obtained from the measured strain data as follows:

The USCGC Polar Sea is assumed to respond approximately the same as a beam in plane bending when it impacts a heavy ice feature, as shown in Figure 3. The bending moment at each instrumented station is calculated from the measured bending strains and the structural properties of the vessel using the following classical bending moment formulae:

Frame 55 $M=(\varepsilon_{01}-\varepsilon_{03})(E)(I)/(D)$

Frames 39, 86, 128 $M=(\varepsilon_{01})(E)(I)/(Y)$
Cant Frames 17, 27, 35, 44

M = bending moment (-ve. if 01 deck is in compression)

ε_{01} = average bending strain in 01 deck at instrumented station

ε_{03} = average bending strain in 3rd deck at instrumented station

E = elastic modulus of the deck plating

I = transverse sectional inertia

Y = distance from the neutral axis to the 01 deck

D = vertical distance between 01 deck and 3rd deck

The deck bending gauges located on the centre line were not used in the bending moment calculation, because local stress fields occurred when the ice force was located at the station containing these gauges.

Figures 10 to 12 illustrate the calculated longitudinal bending moment distributions for the three principal phases of a ramming event: initial impact, ride up phase, and beaching phase. The maximum bending moment occurs at approximately Frame 55 for the initial impact and at Frame 85 for the ride-up and sliding phase. The bending moment diagram crosses the zero line at cant Frame 27 during the impact phase and at cant Frame 44 for the other two phases. The points at which the bending moment are calculated from the measured strain are illustrated on the figures along with a cubic spline fit of this data. Selected locations at which the bending strain was measured are also indicated on the figures. The bending moment diagrams illustrate a small positive bending moment (01 deck in tension) forward of cant Frame 44. This indicates an overhang of the bow forward of the ice and contact zone.

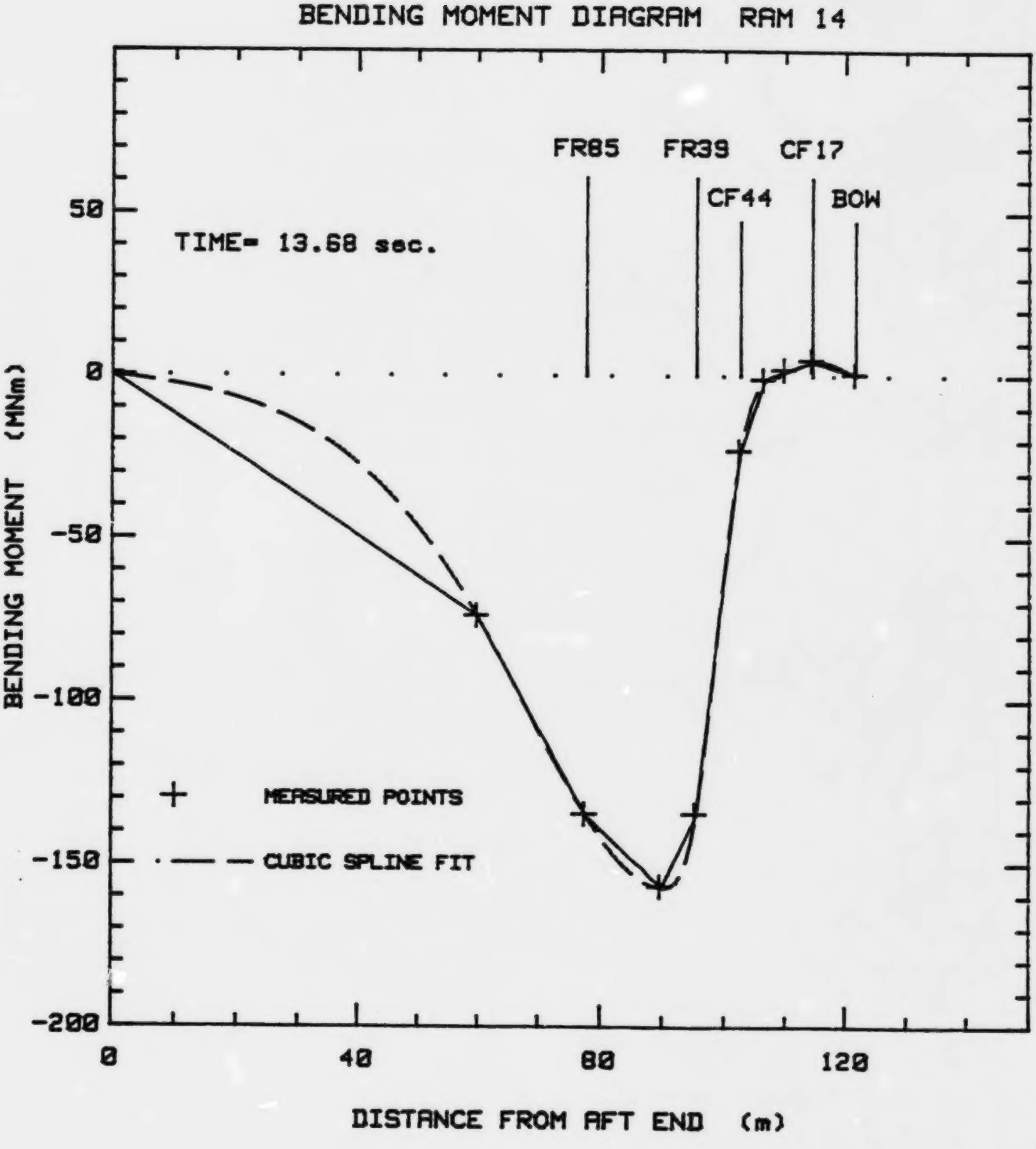


Figure 10 Initial Impact Phase-Bending Moment Diagram Ram 14

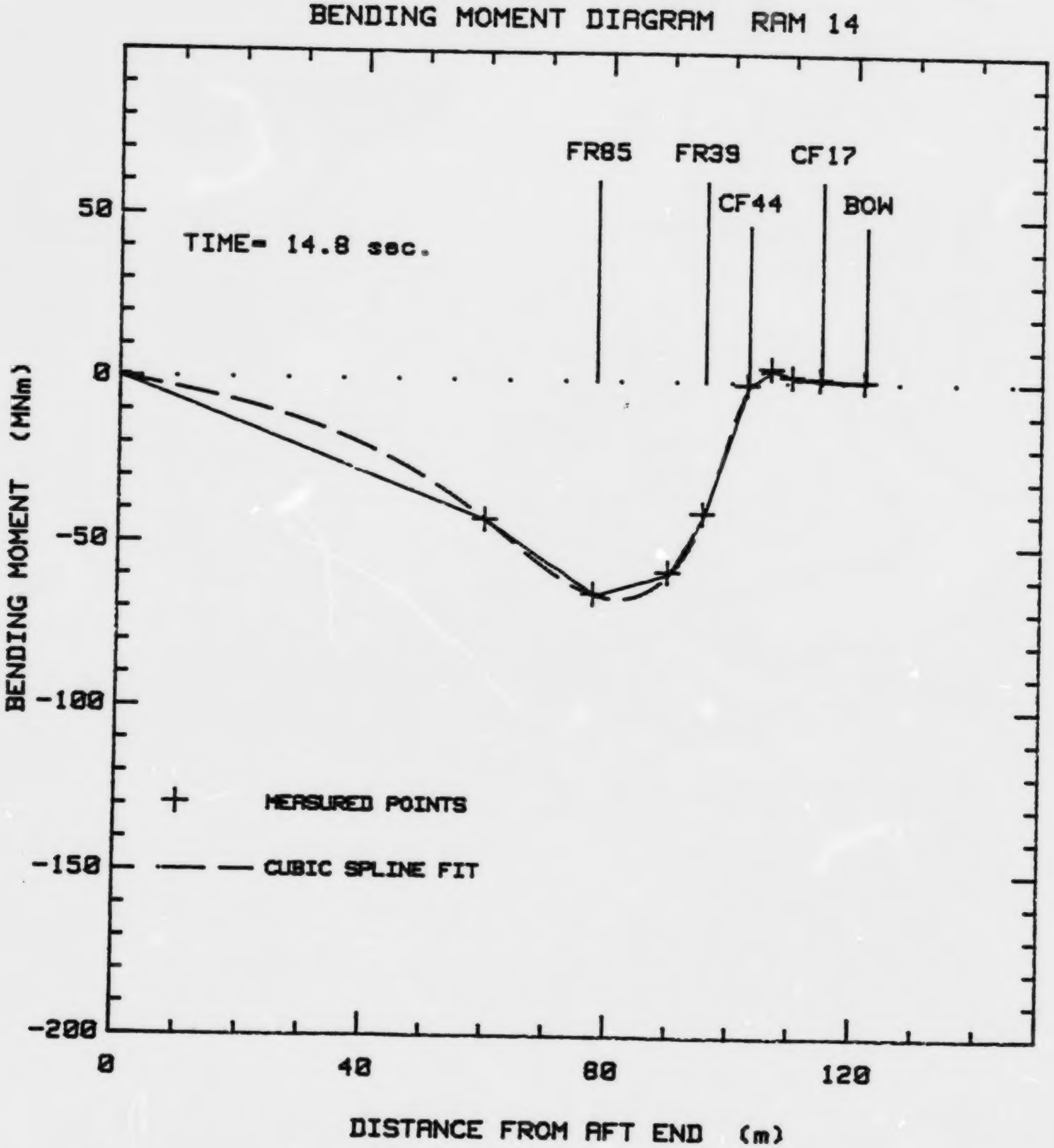


Figure 11 Ride-Up Phase-Bending Moment Diagram Ram 14

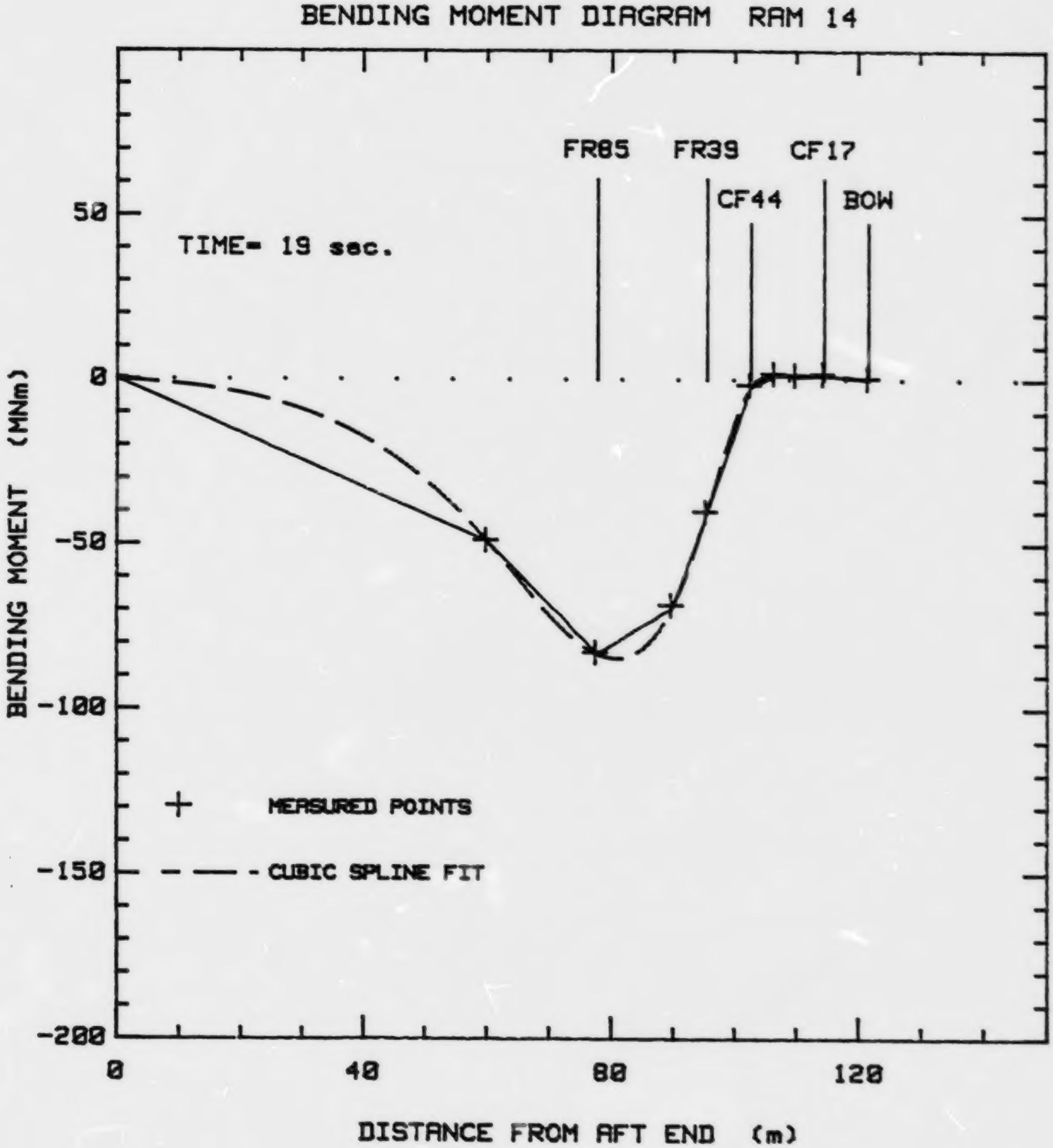


Figure 12 Beaching Phase-Bending Moment Diagram Ram 14

Shear force values are calculated from the slope of the bending moment diagram as follows:

$V_x = (M_2-M_1)/(X_1-X_2)$;

V_x = the shear force at the longitudinal location half way between the stations where bending stresses were measured, i.e., at $x=X_1 + (X_2-X_1)/2$

M_1 = the bending moment at $x=X_1$

M_2 = the bending moment at $x=X_2$

X_1 = the longitudinal location of bending moment M_1

X_2 = the longitudinal location of bending moment M_2

$X_2>X_1$

Figures 13 to 15 illustrates the calculated longitudinal shear force distributions for the three principal phases of a ramming event: initial impact, ride up phase, and beaching phase. The shear force diagram forward of the superstructure governs the value of the global ice force on the bow of the Polar Sea. Any approximations made aft of this location do not affect the value of this force.

The shape of the shear force diagram (slope of the bending moment curve) is dependent on the vertical loading on the structure. The slope of the bending moment diagram (magnitude of shear force) is a maximum between Frame 39 and cant Frame 44.

The vertical force on the bow is calculated by the addition of the absolute value of the shear force before and aft of the location of the ice force as illustrated in Figure 3.

This procedure was repeated for every time step (0.01 seconds) for the duration of the ramming test (25 seconds). Representative rams were analysed in this manner onboard the vessel, using preliminary estimates of the sectional inertias and locations of the neutral axes. Figure 16 illustrates the vertical bow force time history for the ram corresponding to the bending moment and shear force diagrams illustrated previously (Ram 14). The vertical bow force time history for the most severe ramming event is illustrated in Figure 17. Figure 18 shows the corresponding bending moment diagram for three selected points in time. Figure 19 is a plot of the bow force time history of an impact on a previous bow print. The rise time of the force is relatively long (7-8 seconds) for this event. The corresponding bending moment and shear force diagram for the time at the time of the maximum bow force are illustrated in Figures 20 and 21 respectively. The calculate bow force time history for Ram 15 is shown in Figure 22. This is the ram immediately after Ram 14 on the same ridged ice feature.

These results illustrate a similar shape of the bending moment and shear diagrams for different ramming events and at different points in time during the ramming of heavy ice features. However, as illustrated in Figure 19, the shape of the bow force time history can vary considerably.

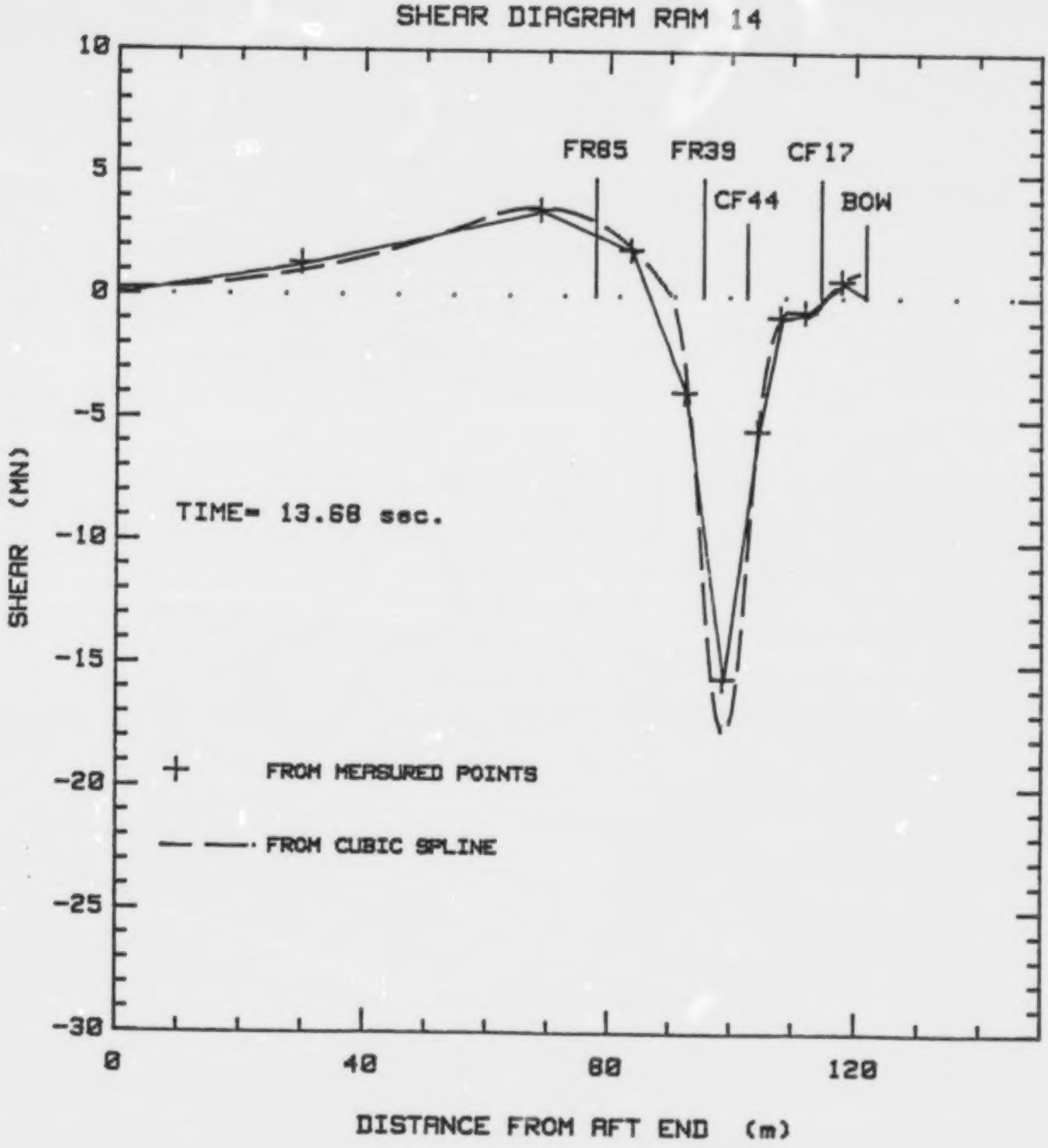


Figure 13 Shear Force Diagram-Initial Impact Ram 14

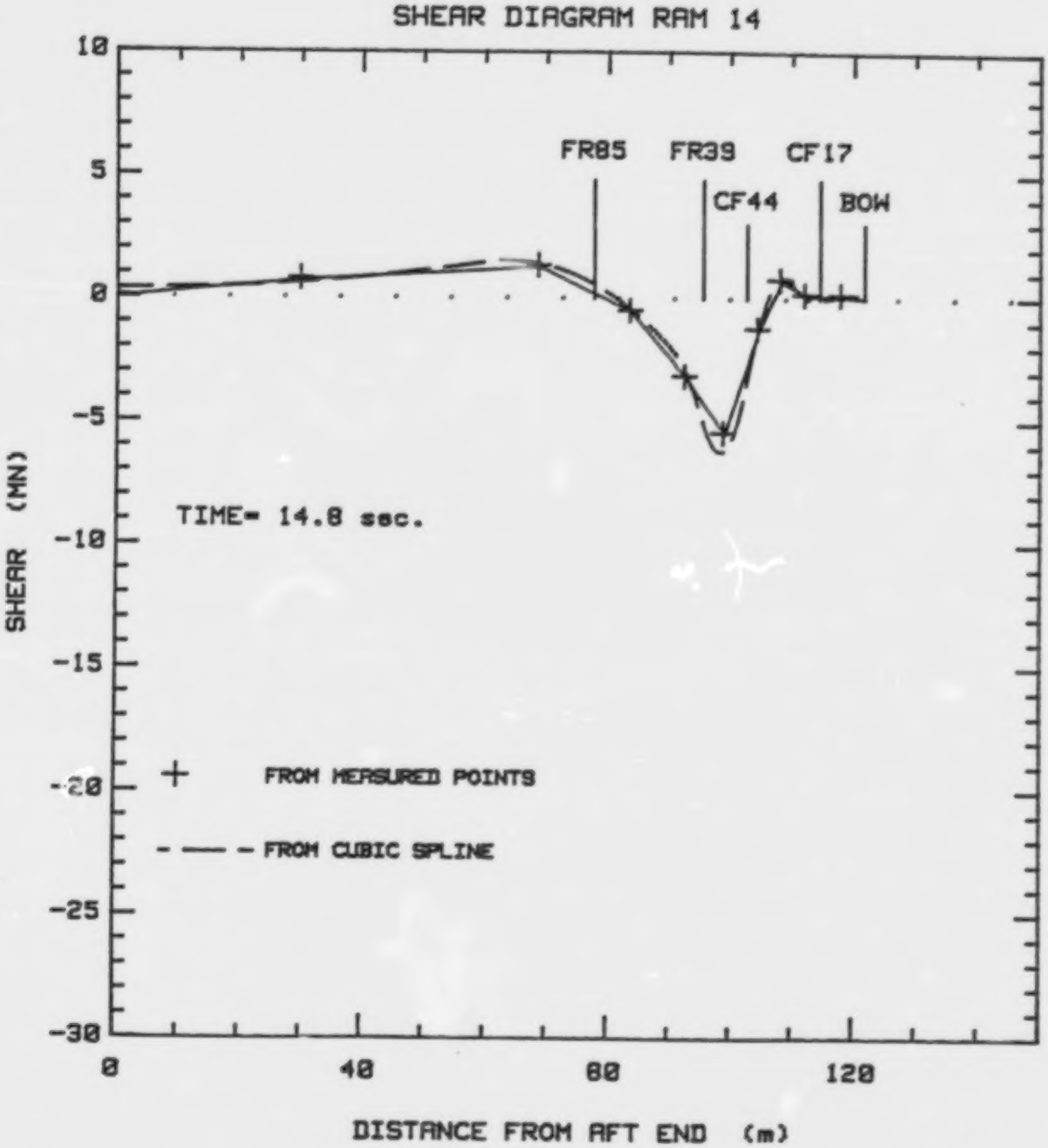


Figure 14 Shear Force Diagram-Ride-Up Phase Ram 14

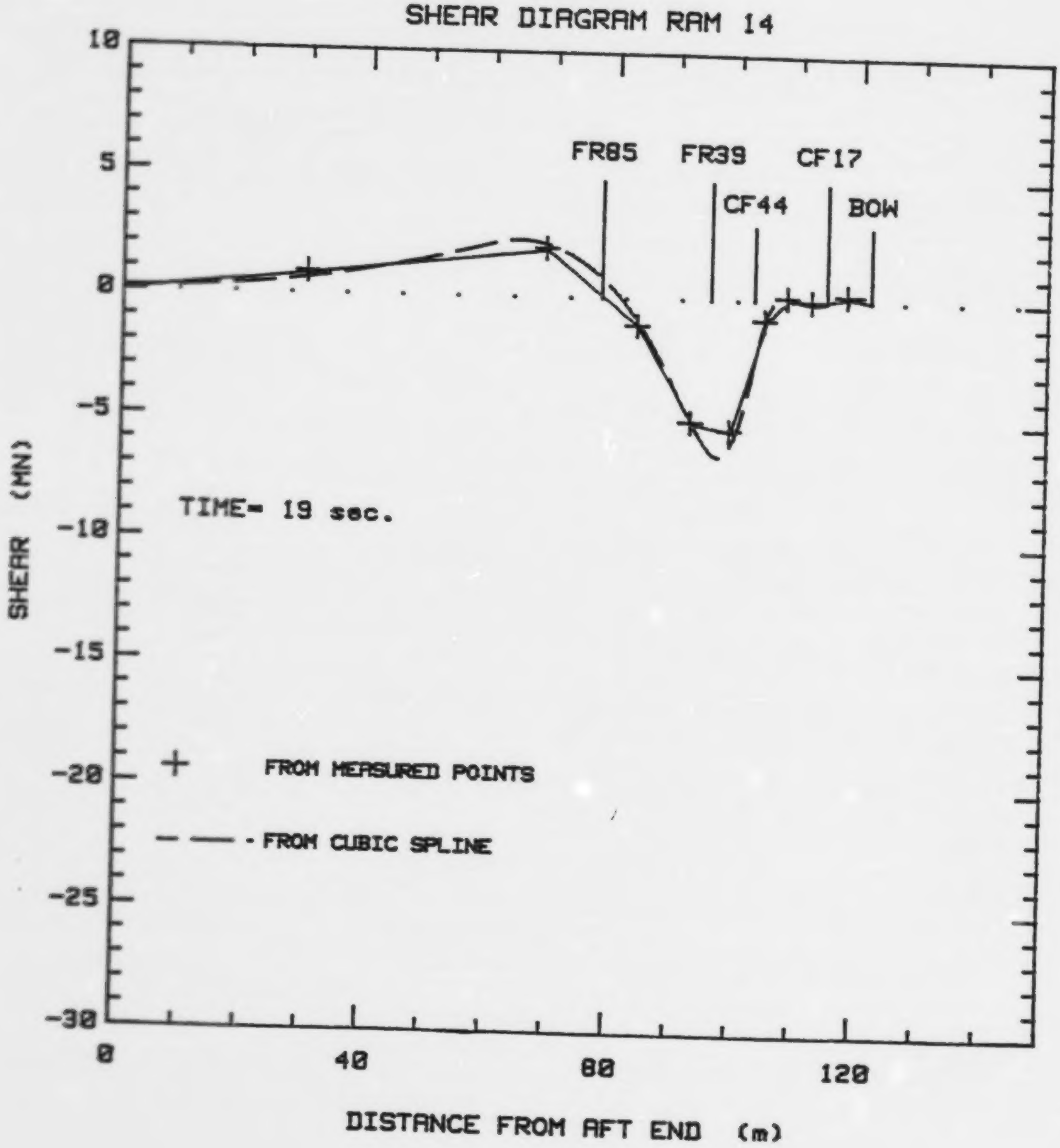


Figure 15 Shear Force Diagram-Beaching Phase Ram 14

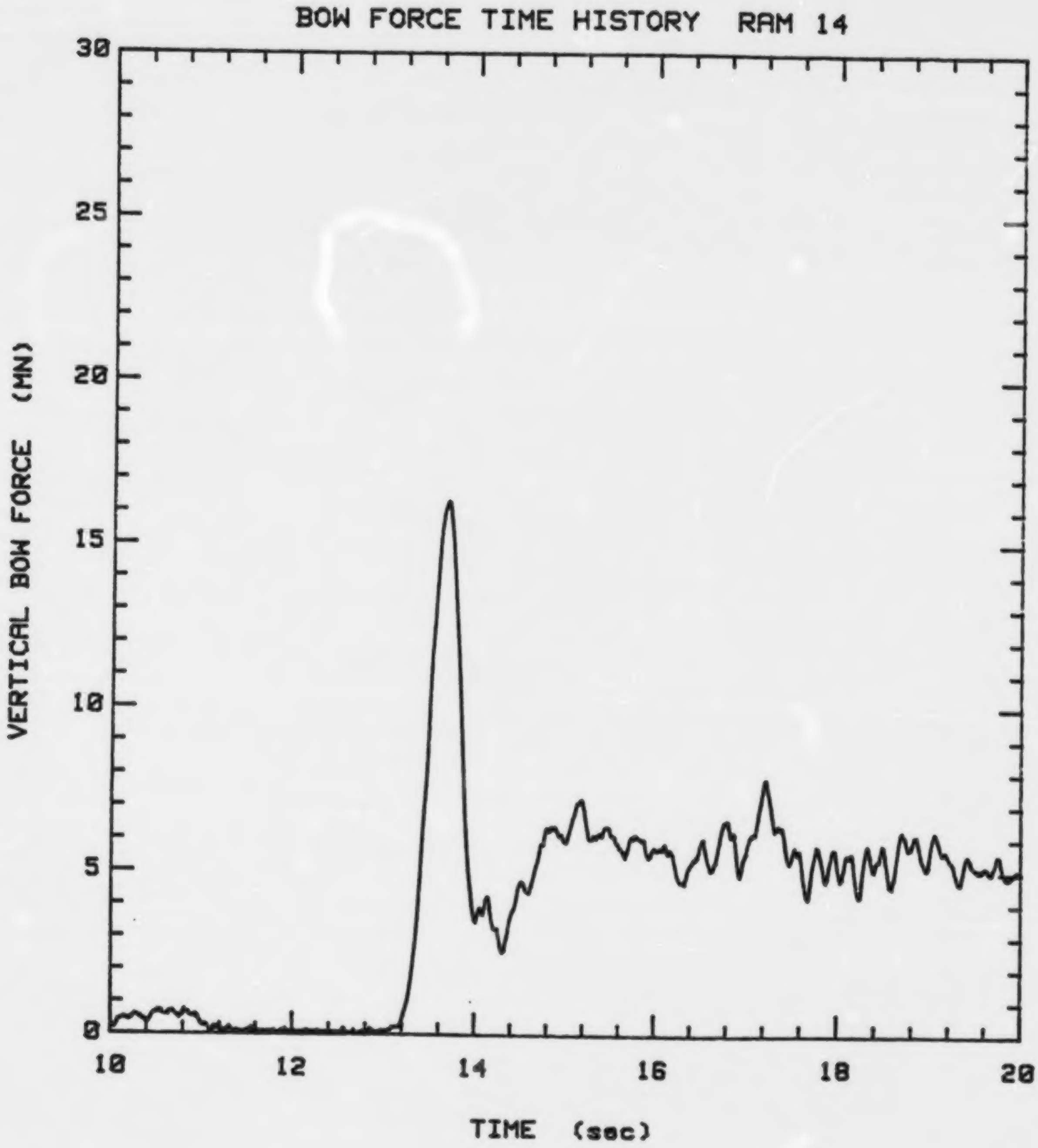


Figure 16 Vertical Bow Force Time History Ram 14

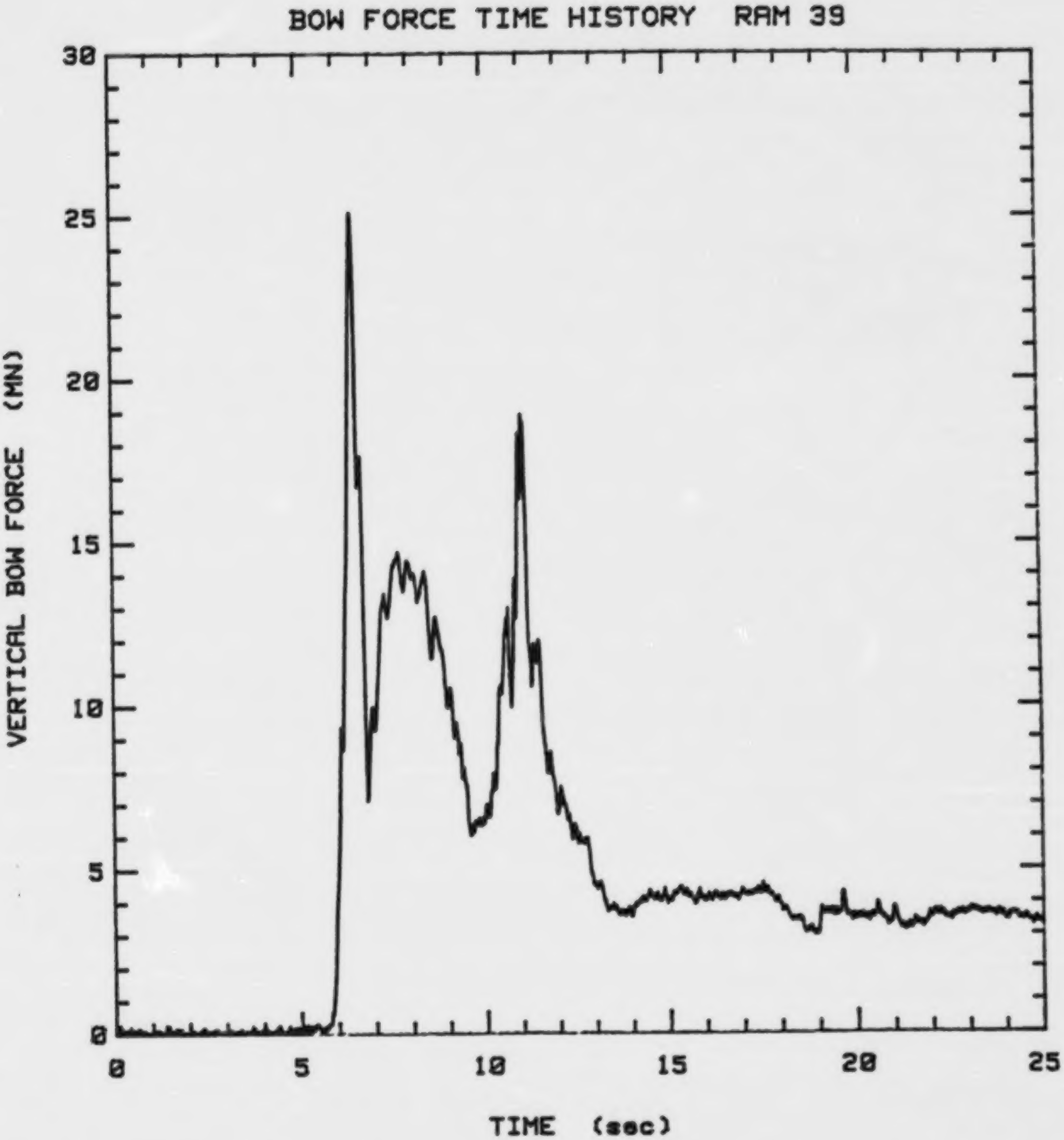


Figure 17 Vertical Bow Force Time History Ram 39

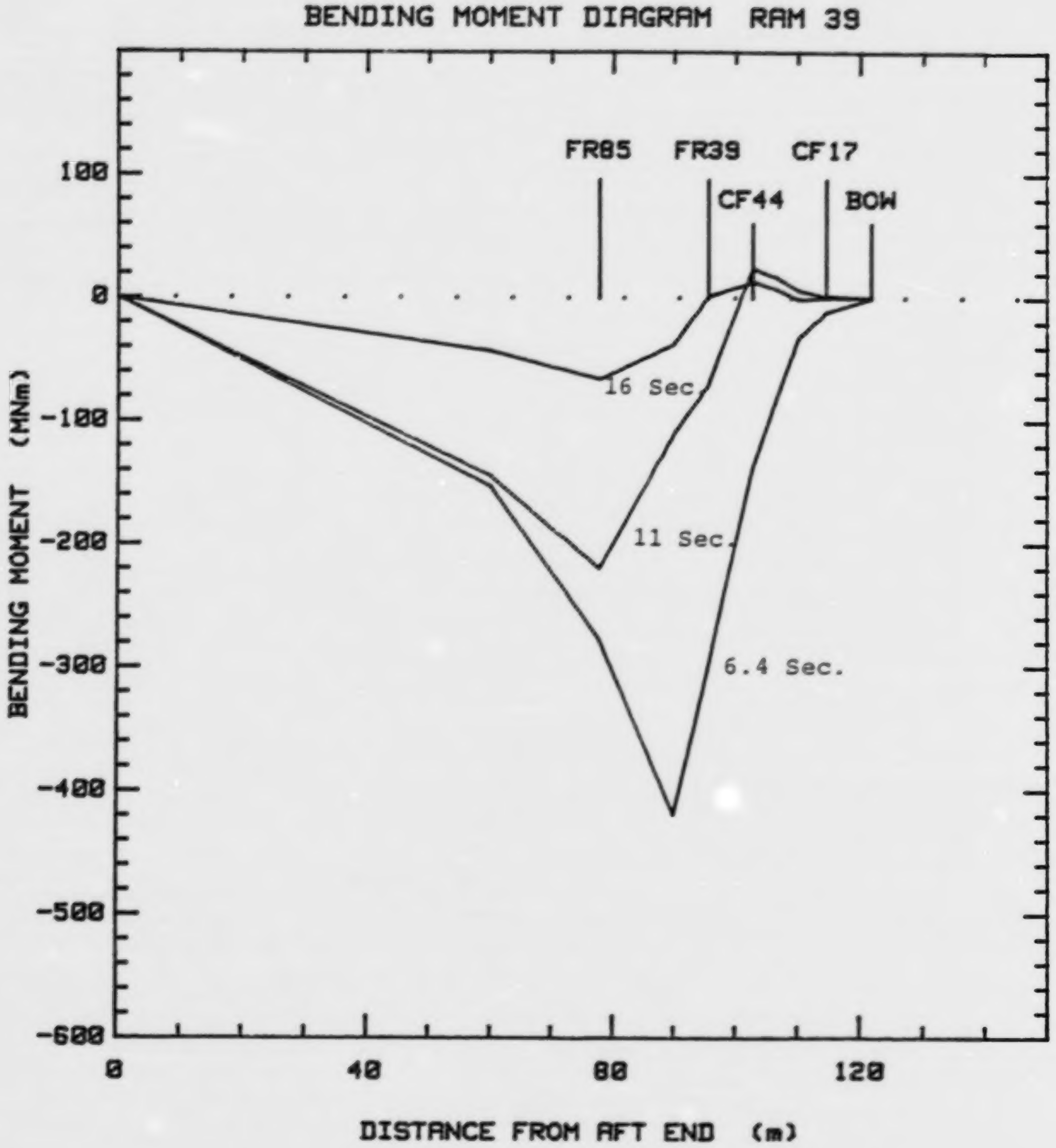


Figure 18 Bending Moment Diagram Ram 39
Three Points in Time

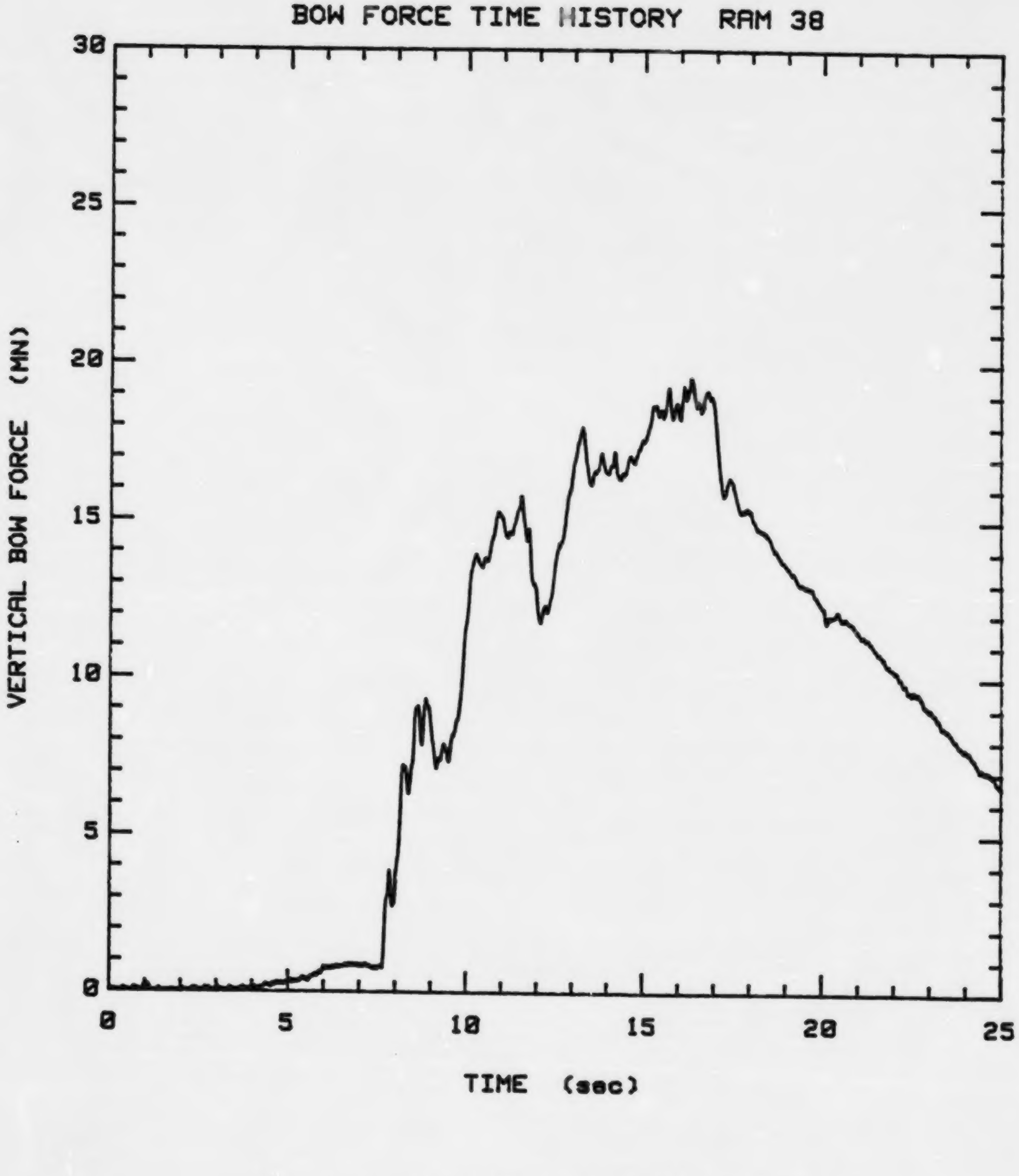


Figure 19 Vertical Bow Force Time History Ram 38

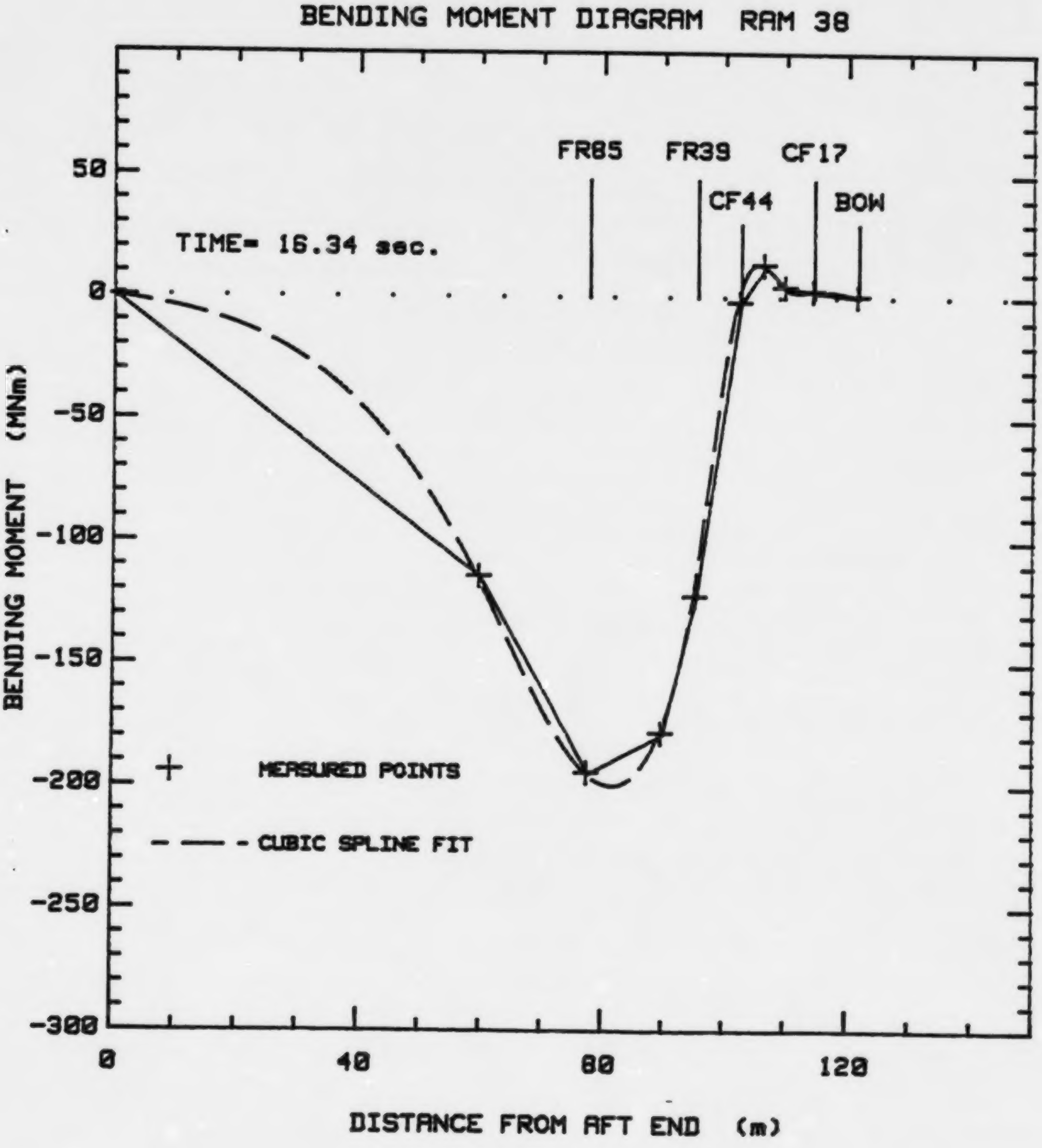


Figure 20 Bending Moment Diagram Ram 38

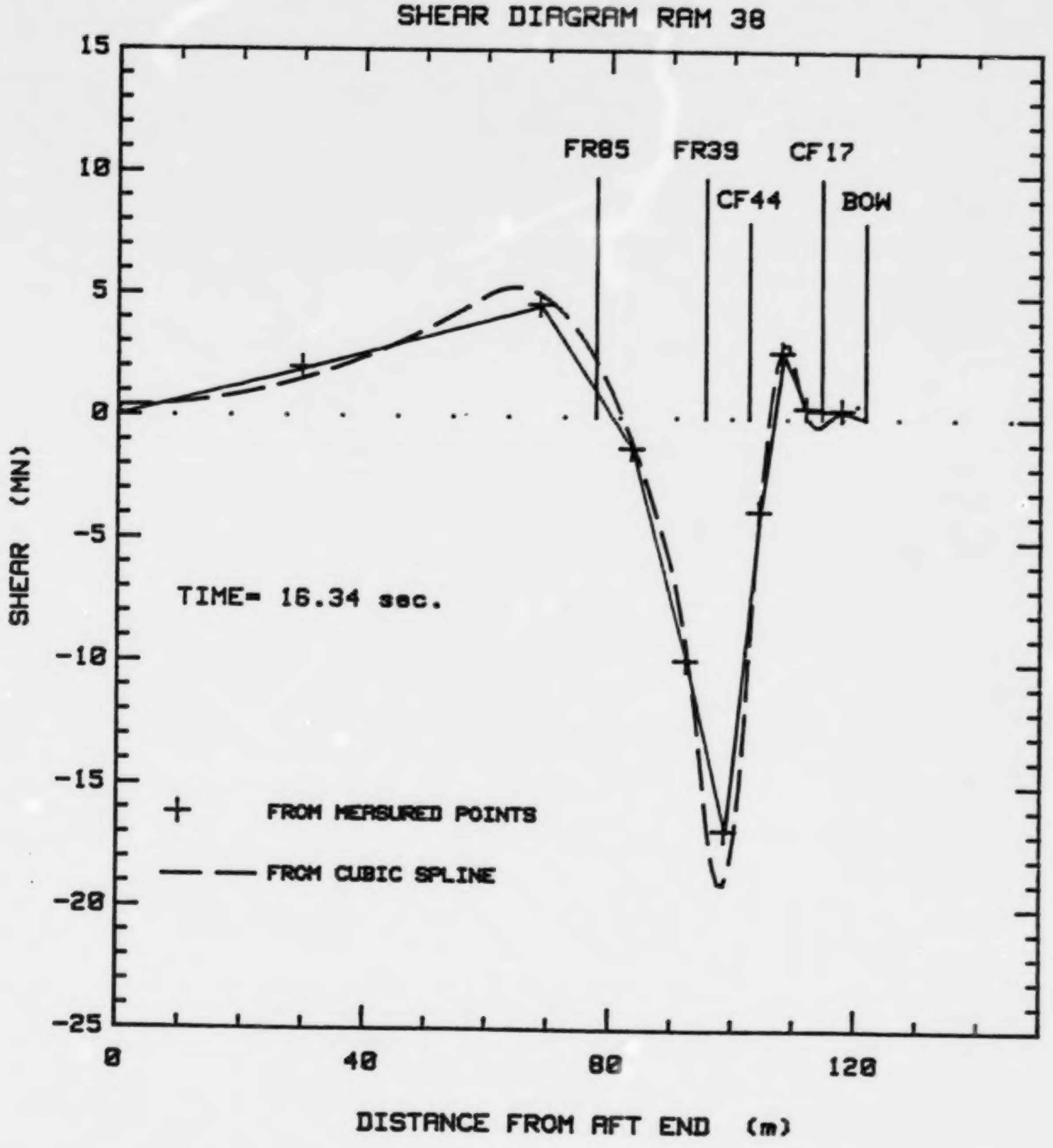


Figure 21 Shear Force Diagram Ram 38

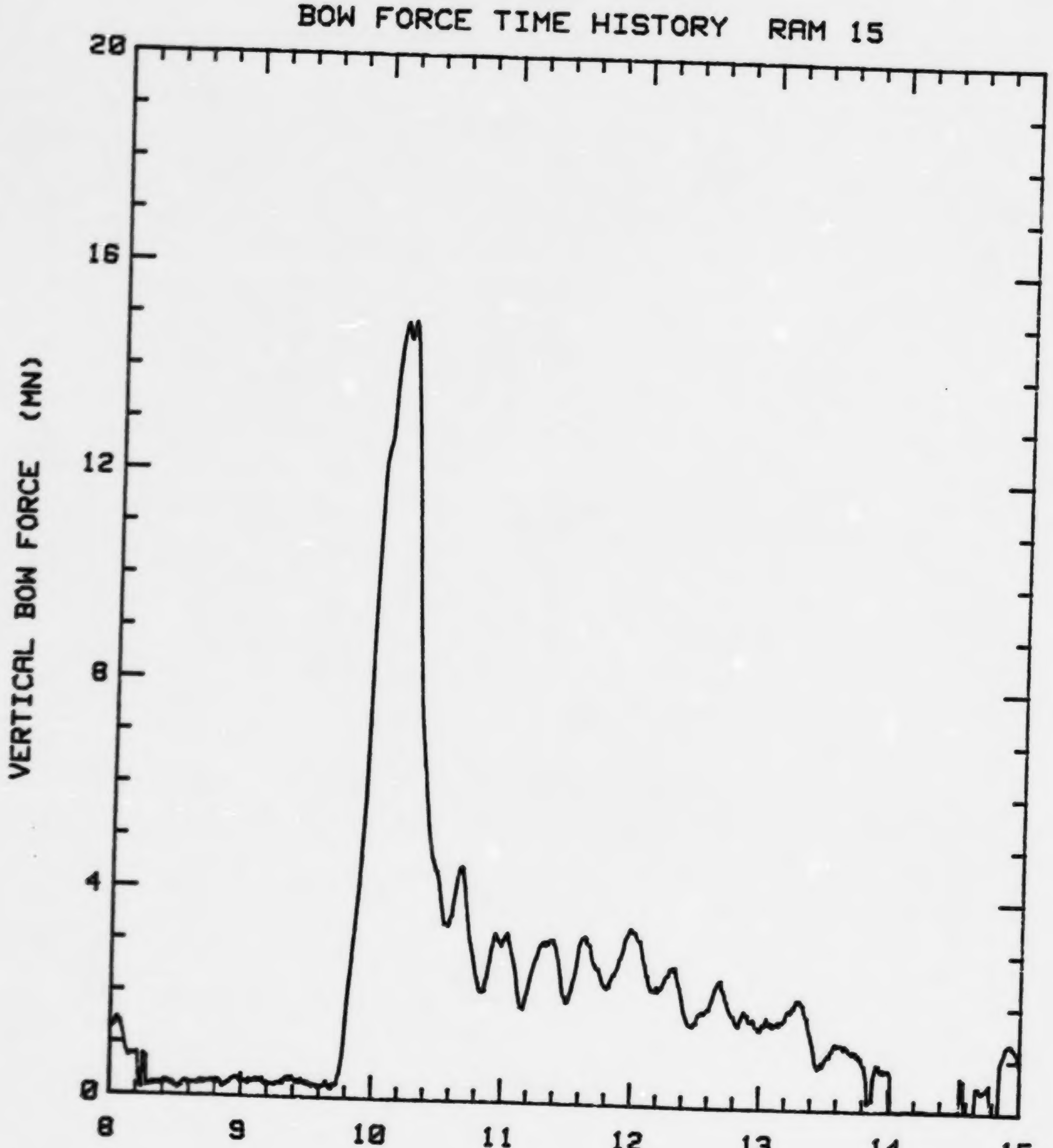


Figure 22 Bow Force Time History Ram 15

The position of the compression gauge on the centre line web frame indicating the maximum compressive stress, was defined as the centre of the vertical ice load. Figures 23 to 25 show the distribution of the stress along the centre line web frame, as measured by these gauges, for the three interaction phases for Ram 14. The peak compressive stress (location of centre of ice force) is measured at cant Frame 28, for the time of maximum force (Figure 23), and the ice force is distributed over approximately 1 m. The peak compressive stress for the ride-up phase is aft of cant Frame 35 and is distributed over more than 3 m. These locations correspond with the location where the bending moment is near zero and the shear force changes sign as indicated in the corresponding derived shear and bending moment diagrams (Figure 13 and Figure 14), as is expected (see Figure 3).

Inertial Forces

If no bending strain is measured forward of the load, the shear force at this location is estimated by the multiplication of the vertical acceleration measurement, and the mass of the bow section forward of the load.

F_i = inertial force
m = mass of section of bow forward of load
a = acceleration of section of bow forward of load

Figure 26 shows the time history plot of the vertical acceleration measured at the bow for Ram 14. The maximum acceleration measured is 1.7 m/sec^2 (0.17 g's). This acceleration if applied to a section of the bow forward of cant Frame 17 would correspond to an inertial force of

$$F_i = (m)(a) = (0.33 \times 10^6 \text{ kg})(1.7 \text{ m/sec}^2) = 0.561 \text{ MN}$$

This value corresponds well with the calculated shear forward of the ice force (0.62 MN) as illustrated in Figure 13. This value is only 4% of the total ice force (16.3 MN). The inertial forces across the ice contact zone are of the same magnitude and therefore do not contribute significantly to the resulting total global bow force.

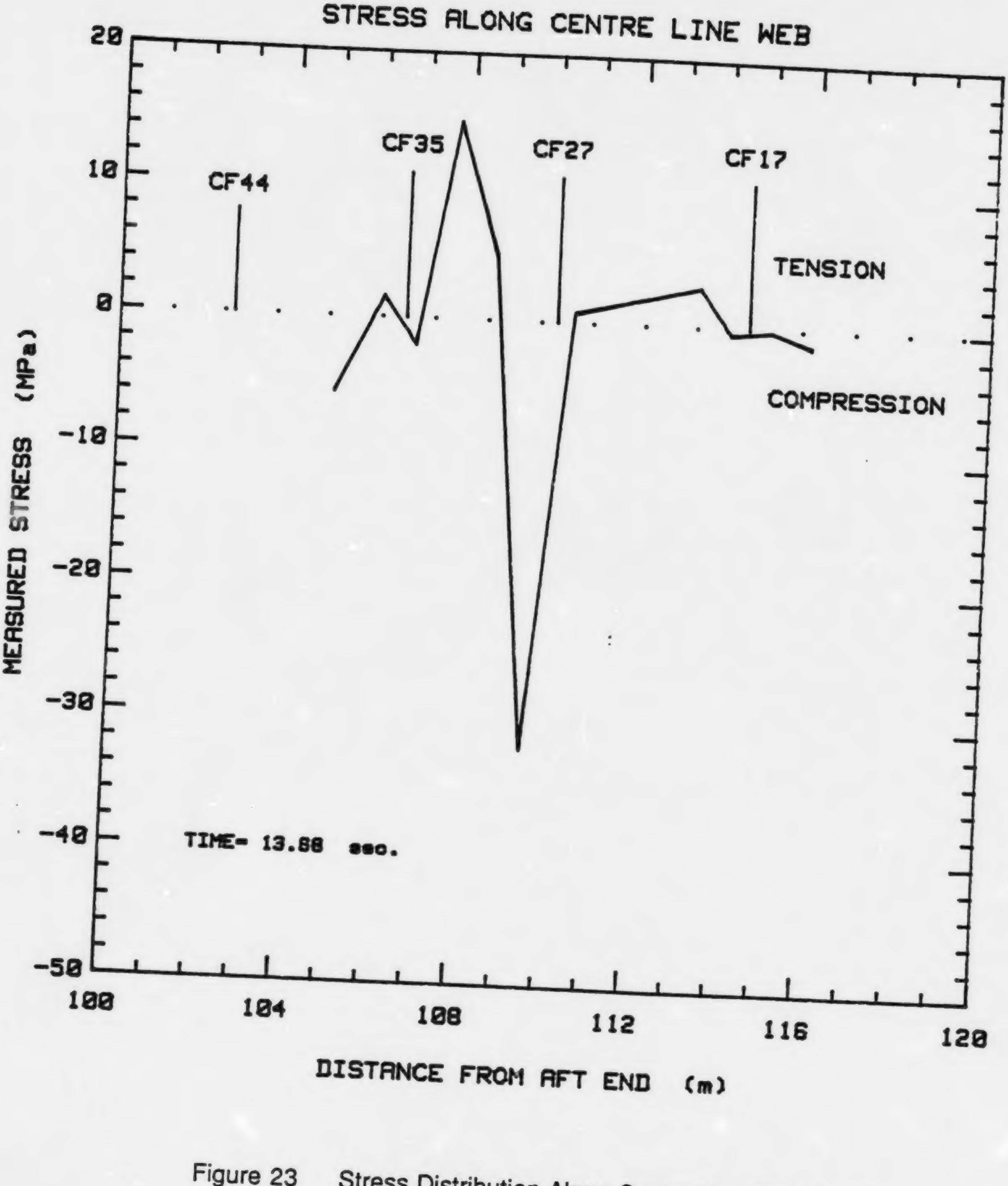


Figure 23 Stress Distribution Along Centre Line Web Frame - Initial Impact Ram 14

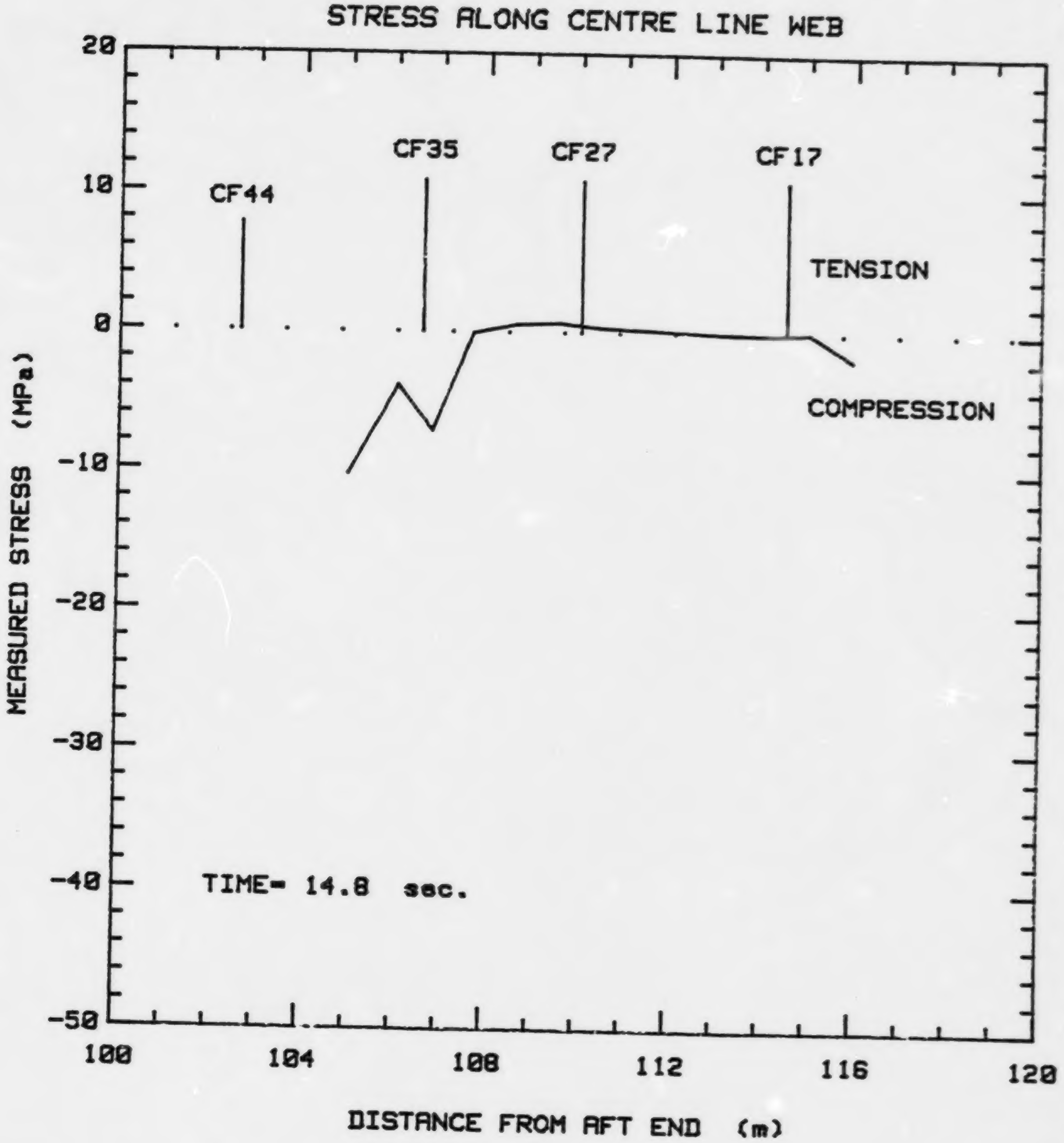


Figure 24 Stress Distribution Along Centre Line Web Frame - Ride-Up Phase Ram 14

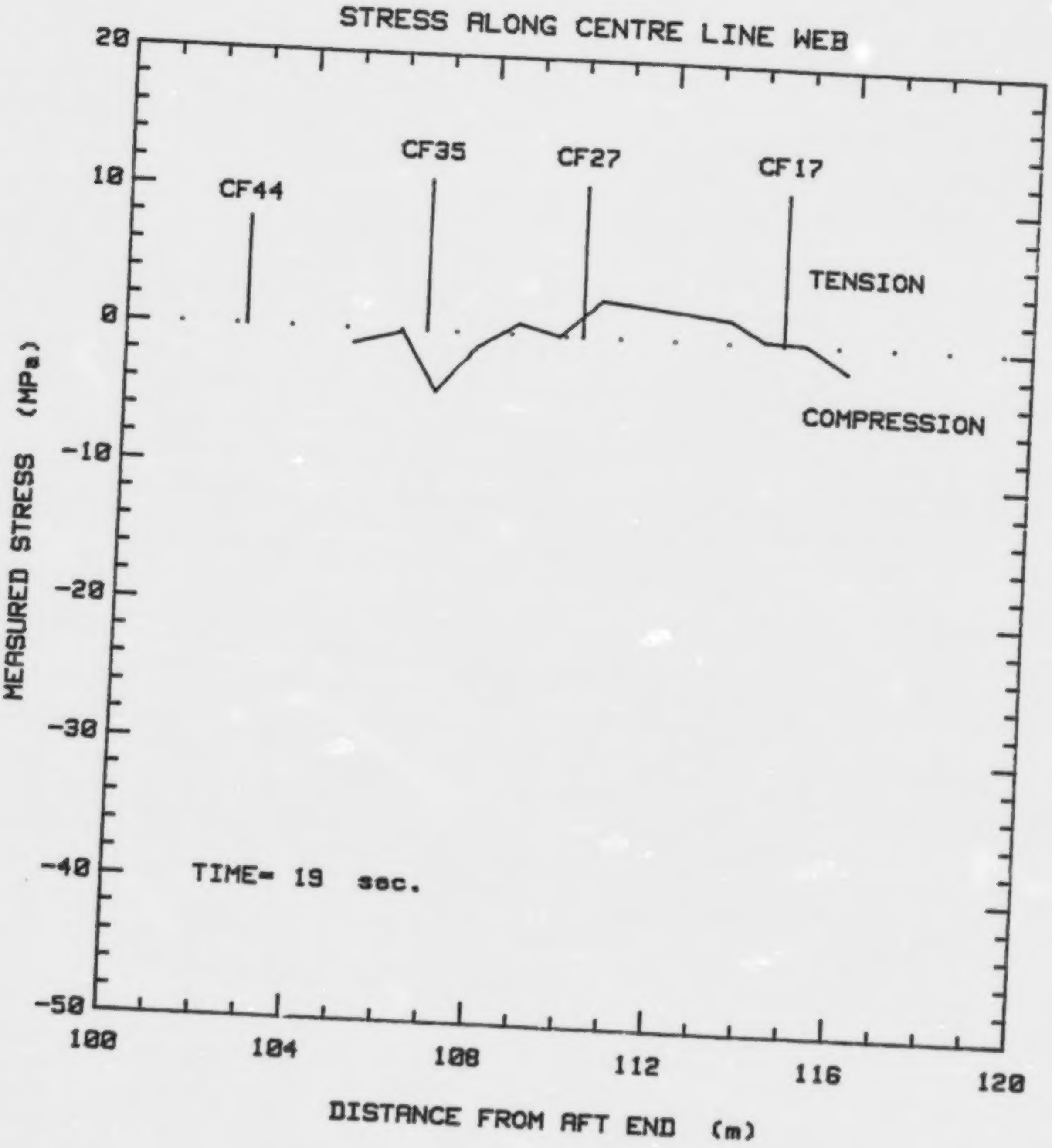


Figure 25 Stress Distribution Along Centre Line Web Frame - Sliding Phase Ram 14

4.1.3 Refinement of Sectional Inertias After Field Test

The onboard data analysis indicated that superstructure contributed to the response of the vessel due to a global ice load. However, the sectional properties for the frames including the superstructure do not affect the calculated vertical bow force. The calculated bow force is a function of the response of the vessel forward of the superstructure, because that is where the shear force is the highest and changes sign (see Figure 3).

The following post analysis was done to determine the effective sectional properties of the Polar Sea:

1. The location of the neutral axis was calculated at frames where bending strain was measured at two levels (assuming a linear stress distribution through the cross section).
2. The difference between the calculated neutral axis location from the bending strains and the ship's drawings was calculated for each cross section. Structural members contributing to the bending of the vessel were estimated, and the cross sectional inertias and neutral axis were re-calculated from the ship's drawings.
3. The shear diagram was integrated over the length of the vessel to determine if the vessel conformed to dynamic equilibrium. This was done as a check on the validity of the re-calculated sectional properties.

Table 3 lists the determined sectional properties of the Polar Sea along with the calculated neutral axis location from the strain measurements.

TABLE 3

SECTIONAL PROPERTIES OF THE Polar Sea

LOCATION	INERTIA (m^4)	NEUTRAL AXIS (m from base line) Calculated	From Measurements
FRAME 128	100	7.41	/
FRAME 86	100	7.86	/
FRAME 55	130	7.7	/
FRAME 39	65.8	8.6	8.7
CANT FRAME 44	26.4	10.6	11.0
CANT FRAME 35	18.0	11.3	/
CANT FRAME 27	10.2	12.3	/
CANT FRAME 17	6.8	13.0	13.0

Note: Inertia includes superstructure where applicable

4.1.4 Total Load Algorithm Compared with Hydrostatic Results

The beaching force calculated from the deck bending gauges was compared to that force calculated from hydrostatics and the trim of the vessel. The beaching force was calculated from the trim of the vessel as follows:

Fb = [(Sin(f))x(LBP)(MTI)/d]x(.009968)

= (246.5)x(sin(f))

Fb = beaching force on bow (MN)

f = Trim angle (longitudinal acceleration in g's, when vessel is stopped and in the beached condition)

LBP = Length between perpendiculars (inches)

MTI = Moment to trim one inch (925 (ft. long tonnes))

d = Distance from ice force to centre of rotation (approximately 158 ft.)

.009968 = convert long tonnes to MN

The comparison was made to obtain an independent check of the load algorithm used in calculating total force. Table 4 lists the results from two selected rams with high beaching forces for comparison. The values compare favorably and are within 5% of each other.

TABLE 4

FORCE FROM HYDROSTATICS AND CALCULATED BEACHING FORCE

RAM NO.	FORCE FROM HYDROSTATIC CURVES (MN)	FORCE CALCULATED FROM BENDING GAUGES (MN)
37	5.4	5.7
39	3.7	3.6

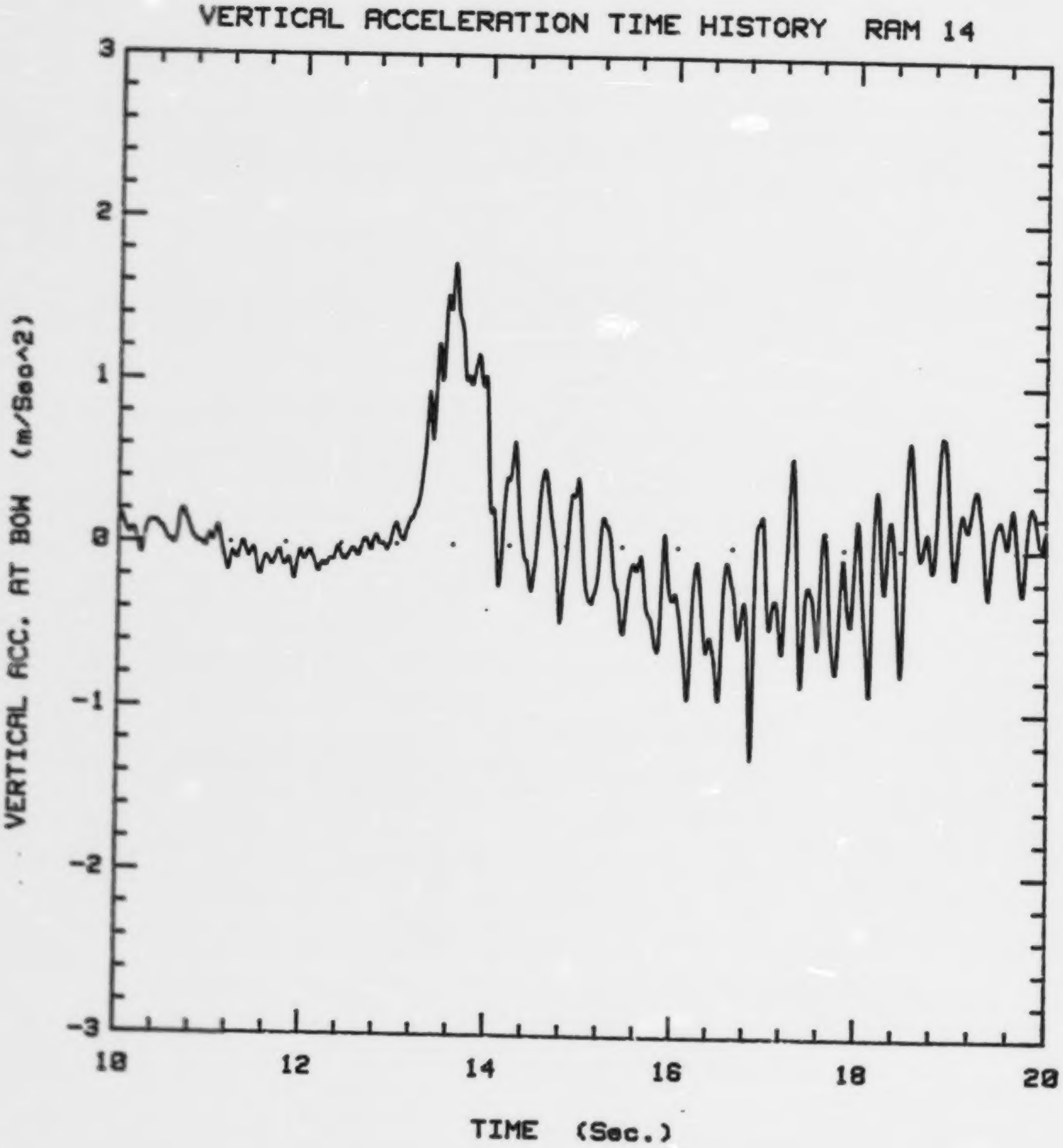


Figure 26 Vertical Acceleration at Bow - Ram 14

4.1.5 Impact Velocity from Stem Bar Compression Gauges

The location of the centre of the ice force (calculated from output of the stem bar compression gauges) during ramming can be used to estimate the impact velocity. A sample plot of the calculated location of the load vs. time is shown in Figure 27. The slope of a line drawn through this stepped curve is an estimate of the velocity of the ice movement along the stem bar. Correcting for the angle of the stem bar an estimate of the linear velocity of the Polar Sea can be made. A comparison between the impact velocity calculated from the location of the load time history, and the velocity measured from the doppler speed log for two rams is listed below:

	IMPACT VELOCITY	
RAM NO.	DOPPLER SPEED LOG (m/sec)	STEM BAR GAUGES (m/sec)
8	3.6	4.4
9	3.5	3.9

The difference in velocities may be due to the nature of the ship ice contact (the ice contact is not exactly a point force moving down the stem bar). However, the values are relatively close.

4.2 Summary of Data Analysed

The program for analysing the strain data was applied to all of the rams. Revisions to the program were added according to the status of the sensors for each ram. Table 5 lists the peak force, impact velocity and peak bending stress for all the ramming tests. A histogram of peak vertical force is illustrated in Figure 28.

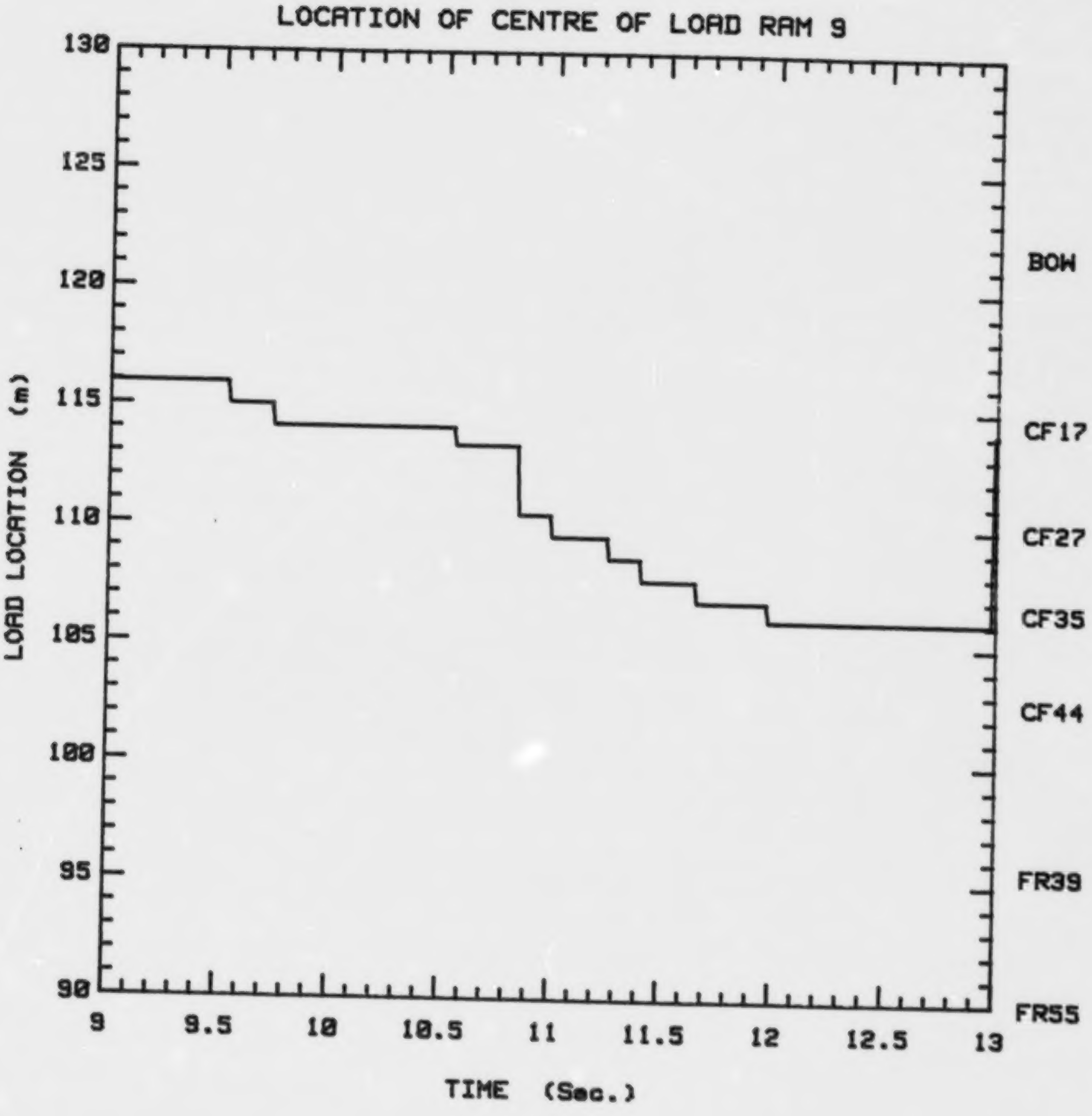


Figure 27 Location of Load vs Time - Ram 9

TABLE 5
SUMMARY OF IMPACT DATA ANALYSIS

RAM No.	IMPACT VEL. (knots)	BOW FORCE		MEASURED BEND. STRESS		
		MAX. (MN)	TIME (Sec.)	MAX. (MPa)	TIME (Sec.)	LOC.
1	8.3	8.6	17.4	-10.5	17.5	FR39
2	8.9	16.8	14.9	-24.4	14.9	FR39
3	8.5	15.3	22.8	-17.3	22.8	FR39
4	5.9	5.6	4.9	-6.9	4.9	FR39
5	8.6	14.2	15.1	-15.4	15.1	FR39
6	5.9	8.1	5.8	-12.0	5.8	FR39
7	6.1	11.4	14.7	-9.1	14.7	FR39
8	7.0	8.2	21.8	-14.2	16.6	FR39
9	7.0	14.1	16.2	-25.9	16.1	FR39
10	7.0	6.8	12.9	-10.3	12.9	FR39
11	8.6	7.2	13.9	-11.7	13.8	FR39
13	4.0	5.3	14.5	-7.2	14.5	FR39
14	4.3	16.3	13.7	-17.6	13.7	FR39
15	5.7	14.9	10.2	-12.9	10.2	FR39
17	8.5	16.5	11.9	-13.8	8.4	FR39
18(1)	6.0	15.0	8.2	-15.9	13.1	FR39
19	4.8	13.0	7.9	-15.1	7.8	FR39
20	6.9	11.6	5.4	-14.2	5.4	FR39
21	8.5	12.6	6.7	-12.5	4.5	FR39
22(1)	6.0	10.8	6.6	-13.7	4.6	FR39
23	8.8	10.0	10.6	-10.4	10.0	FR39
24(1)	7.0	8.6	11.2	-10.5	9.2	FR39
25	7.5	19.7	10.1	-30.1	10.1	FR39
26	9.0	14.9	12.1	-18.7	10.3	FR39
27(1)	6.0	7.7	9.1	-9.7	9.1	FR39
28(2)		9.3	11.7	-10.5	11.7	FR39
29(2)		6.2	4.1	-9.4	6.0	FR39
30(2)		6.9	7.3	-9.6	7.3	FR39
31	1.7	10.9	4.6	-11.2	1.9	FR39
32	0.0	10.2	9.1	-10.5	9.1	FR39
33	11.5	20.9	8.9	-19.5	2.1	FR39
34	10.9	14.3	10.5	-16.9	10.5	FR39
35	6.6	6.9	6.3	-9.3	12.6	FR39
36(1)	9.0	9.4	6.4	-12.7	6.4	FR39
37	1.7	6.6	10.8	-9.9	11.7	FR39
38	6.2	19.5	16.3	-17.1	17.0	FR39
39	8.5	25.1	6.5	-41.9	6.5	FR39
40	7.6	16.1	7.1	-22.0	7.1	FR39

(1) DATA FROM BRIDGE VELOCITY INDICATOR
(2) SPEED DATA NOT AVAILABLE

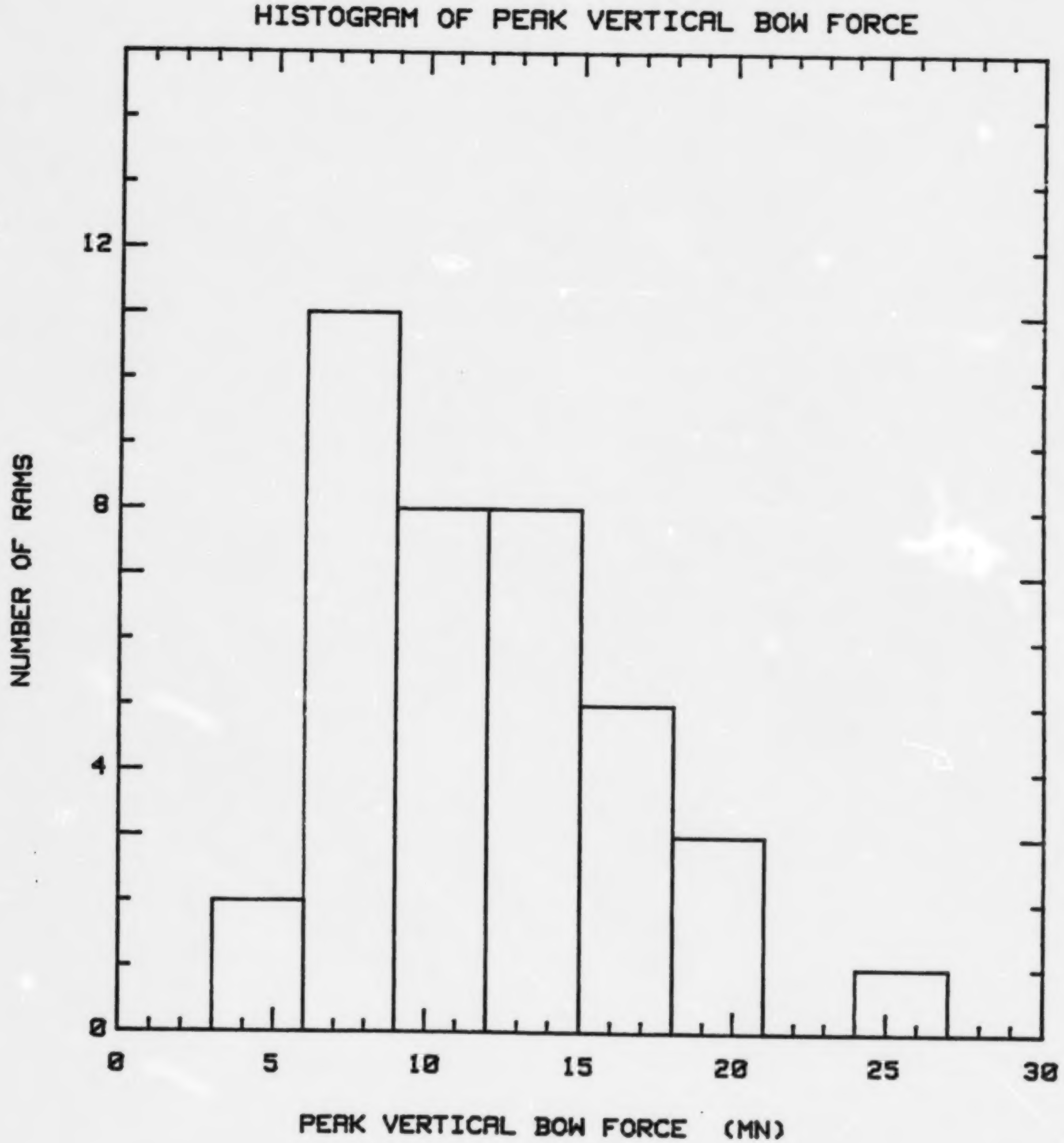


Figure 28 Histogram of Peak Bow Force

4.3 Dynamic Magnification

The dynamic magnification is defined as the ratio of the amplitudes of response produced by a statically applied load and by a dynamically applied load both with the same magnitude [15].

$$DM=X_1/X_1$$

DM=Dynamic Magnification
X_1 = Amplitude of Response from Dynamic Load
X_2 = Amplitude of Response from Static Load

The dynamic magnification is related to the ratio of the natural period of the vessel and the duration of the impact. For a single degree-of-freedom system (rigid body motion) and a half sine wave input force, the dynamic magnification is less than 15% if this ratio is greater than 2.2 and approaches 1 as the ratio increases. The Polar Sea has a natural period of approximately 0.33 seconds; the duration of the impact force is approximately 0.8 seconds. This corresponds to a ratio of

$$\text{Impact Duration/Natural Period} = 0.8/0.33= 2.42$$

Therefore, if the Polar Sea is idealized as having ridged body motion (i.e., single degree-of -freedom system), the dynamic magnification will be less than 15%. However, from the designers point of view any attempt to determine the dynamic magnification factor is only academic. The designer needs the actual magnitude of the dynamic force and the response associated with it. The methodology employed in these tests and the corresponding figures presented in this report include the dynamic effects.

5. COMPARISON OF POLAR SEA DATA WITH OTHER DATA

There is a very limited amount of published data on global ice loads on icebreakers, because of the high cost associated with full-scale testing. There is some limited data from the S.S. Manhattan [16]; in this report it was estimated that there was a bow force of 102 MN (11,500 tonnes) for a 5 knot ram. The most extensive amount of data published to date is that from the October 1983 Kigoriak Impact Tests [13], which includes figures of longitudinal bending moment and shear force diagrams as well as bow force time histories. This data collected from the Polar Sea tests is of a similar format and lends itself for comparison with the Kigoriak data. In this section, the results from the Polar Sea tests are compared with the October 1983 Kigoriak test data, as well as the predicted results from analytical models.

The Kigoriak has the following particulars:

Length O.A.	91 08 m
Length B.P.	79 34 m
Breadth MLD	15.25 m
Depth MLD	10.00 m
Draft, Design	8.53 m
Design Displacement	6806 tonnes (S.W.)
Power	16,800 BHP

5.1 Peak Vertical Bow Force vs. Impact Velocity

Figure 29 illustrates the relationship between vertical bow force and impact velocity for the Polar Sea. All the available data is included for every ice feature encountered. The figure also shows the prediction of Johansson, et al., [14] and the envelope curve derived from the Kigoriak 1983 Impact Tests [13]. The curve derived from the Kigoriak tests overestimates the force for all ranges of speed. Johansson's prediction is a good upper bound for ramming velocities between 2.0 and 4.5 meters per second, but overestimates the force for impact velocities above 4.5 meters per second.

The formulas used from [13] and [14] relate the total bow force as a function of stem angle, displacement, and impact velocity, but do not allow for a difference in the flare angle or other geometric considerations of the bow. The bow flare angle for the Kigoriak is approximately 10° and that for the Polar Sea is 35°. The lower flare angle of the Kigoriak causes high contact areas upon impact resulting in higher bow forces than the Polar Sea for approximately the same velocity. The higher force applied by the Kigoriak is distributed over a larger area, whereas the higher flare angle of the Polar Sea applies a force to the ice in a more concentrated area. The difference in bow flare angle can contribute significantly to the bow force/velocity relationship by its influence on contact area and therefore should be accounted for in analytical relationships between bow force and impact velocity.

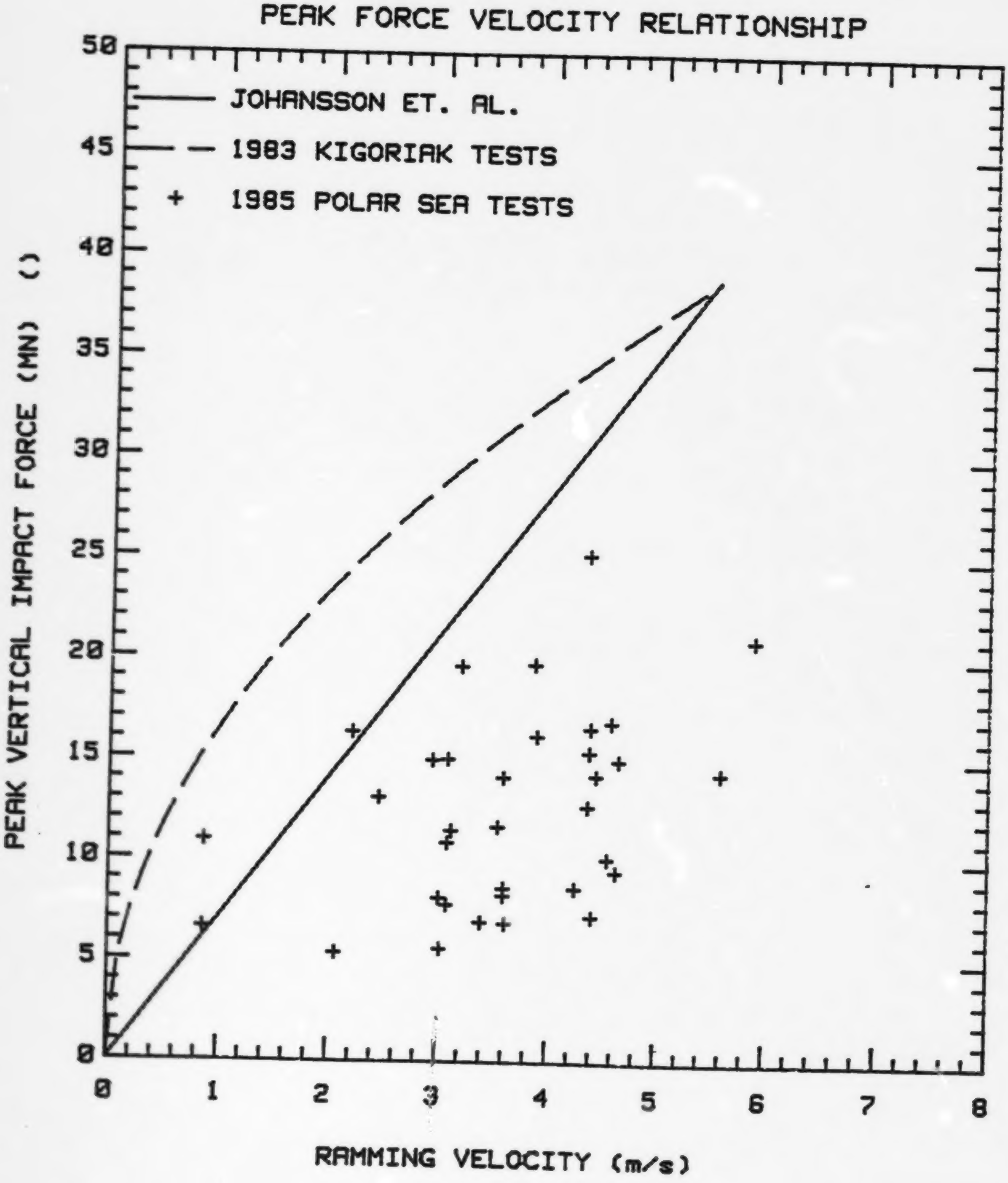


Figure 29 Peak Bow Force vs Ramming Velocity

5.2 Vertical Bow Force Time Histories

A time history plot of vertical bow force for the Polar Sea and the Kigoriak are illustrated in Figure 30 and Figure 31 respectively. The Kigoriak's plot shows the force dropping from 23.5 MN to 0.0 MN, then rapidly increasing up to 12 MN. This feature indicates a separation of the bow-ice interface. The Polar Sea plots do not indicate this feature on any of the rams analysed to date.

The Polar Sea had approximately 1.7 times the displacement, during its full-scale tests, than that of the Kigoriak during the conduction of its impact tests. The impact duration (length of time of the first bow force peak) is approximately 0.48 seconds and 0.80 seconds for the Kigoriak and the Polar Sea respectively. This value is approximately the same as the ratio between the impact durations (1.67). This implies a linear relationship between impact duration and displacement and should be investigated further. In both plots there is a relatively constant force (beaching force) at the end of the ram.

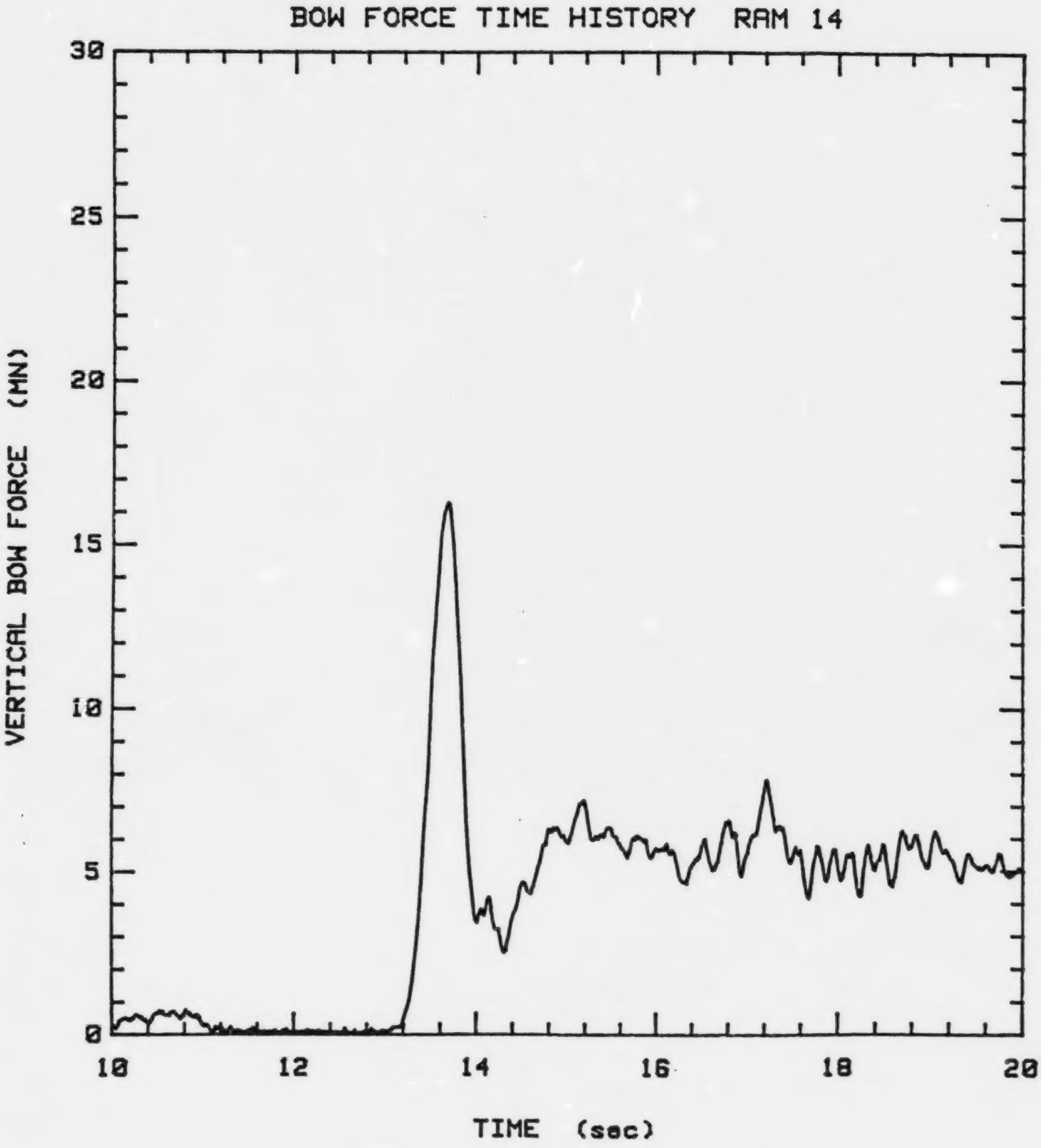


Figure 30 Bow Force Time History Ram 14

```
KIGORIAK ICE IMPACT TESTS  1983       PRGM. KR300_50
                                      VERSION 5.3

Test:  KR426
Buffer Number: 1

Baseline From Buffer: 1     Time 5 to 50

BOWF    Min =  -1.19    Max =  23.48    Ref =  23.48   MN
```

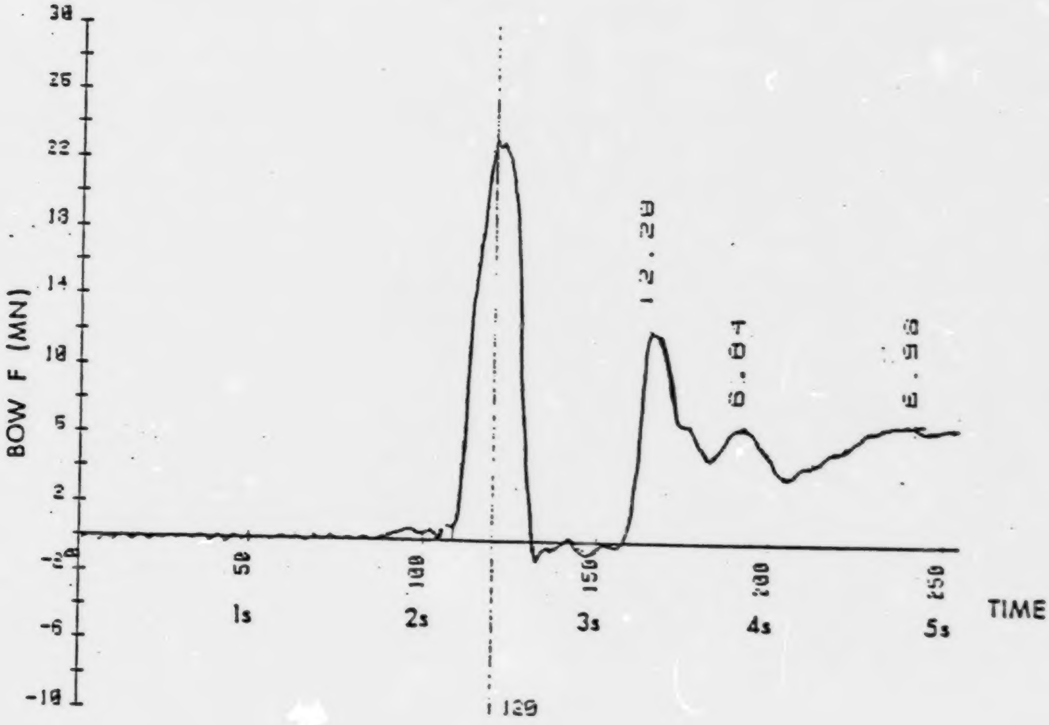


Figure 31 Kigoriak Bow Force Time History Ram KR426

5.3 Longitudinal Bending Moment and Shear Diagrams

The bending moment distributions for the Polar Sea and the Kigoriak, at the time of maximum force, are shown in Figure 32 and Figure 33. The plots are similar in shape but have the following differences:

1. The Polar Sea diagram indicates the bending moment forward of the location of the load (positive bending moment) whereas the Kigoriak diagram ends at the estimated location of the load centre. The instrumentation used in the Polar Sea tests allowed for measurements of the bending moment forward of the location of the ice force. In the Kigoriak data analysis the ice load is approximated as a point load and the bending moment diagram was extrapolated to this estimated location.

2. The maximum bending moment on the Polar Sea occurs further forward (approximately 75% of the length of the vessel forward of the aft end) than the Kigoriak's (approximately midship).

The shear distribution for the Polar Sea and the Kigoriak, at the time of maximum force, are shown in Figure 34 and Figure 35 respectively. The sign convention for shear is in the opposite sense for the two figures. The following differences are observed between these graphs:

1. The Polar Sea diagram illustrates the shear value forward of the centre of the load (0.61 MN); the Kigoriak's diagram does not indicate this.

2. The shear value changes sign over approximately fifteen meters in the Polar Sea diagram. The Kigoriak diagram extrapolates the shear force to the estimated location of the ice force and the bow force is equated to the shear force at this point. The Polar Sea bow force would be overestimated if it was equated to the shear force at the location of the centre of the ice force; because the measured location of the centre of the ice force is forward of the maximum shear force as illustrated in Figure 23. Therefore, in estimating the global ice force from the shear force distribution, the location of the ice force should not be treated as a point load. The shear force should be measured or calculated from bending moment measurements at locations aft and forward of the ice contact zone.

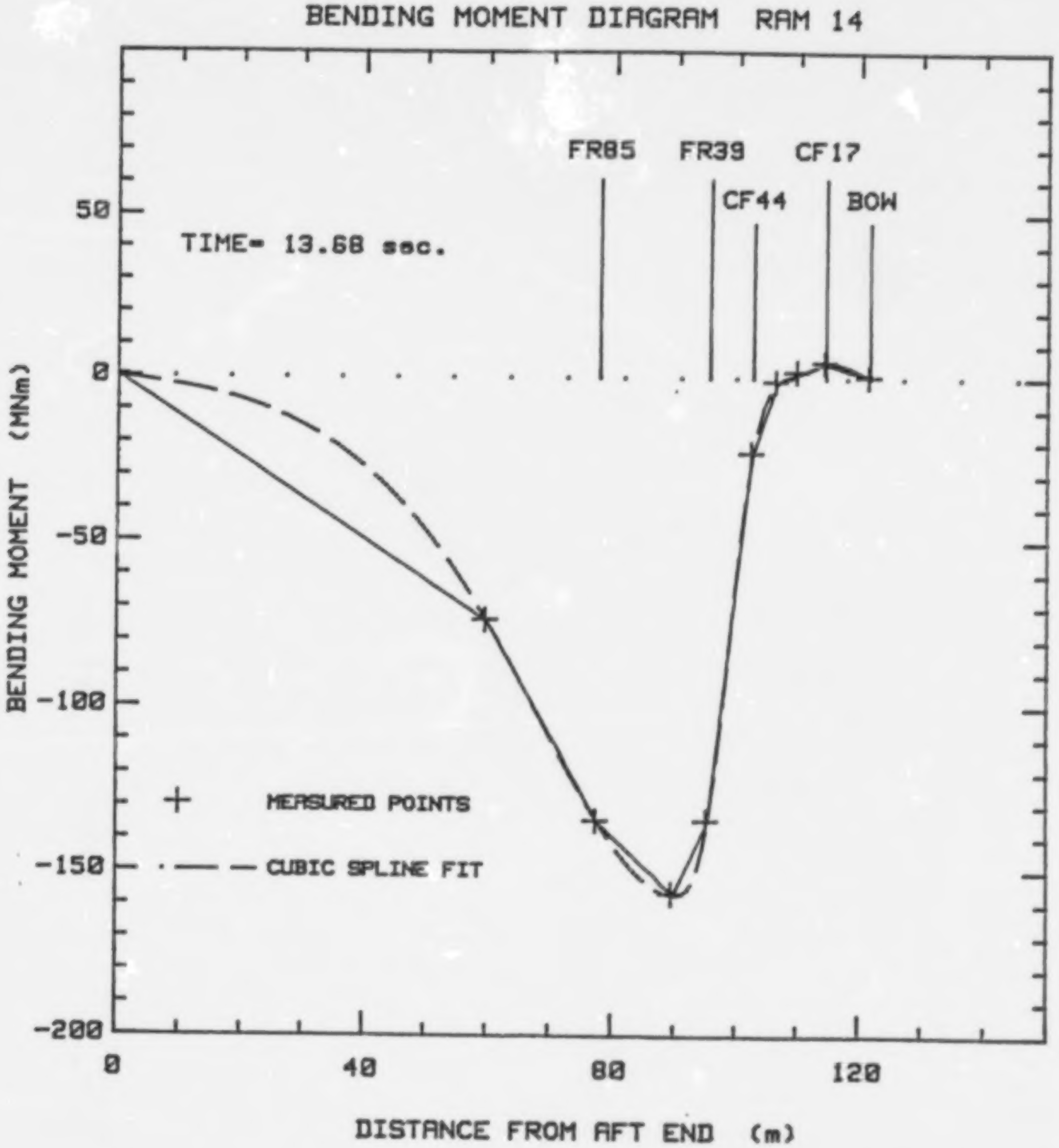


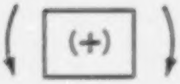
Figure 32 Typical Bending Moment Diagram for the Polar Sea

```
KIGORIAK ICE IMPACT TESTS. 1983 .     PRGM. KR300_501
                                      VERSION 5.3
Test: KR426
Buffer Number: 1

Baseline From Buffer 1  Time 5  to 50

   Time= 124   Fr12=-453   Fr17=-537   Fr20=-481   Fr24=-302
   Time= 123   Fr12=-460   Fr17=-547   Fr20=-481   Fr24=-306
   Time= 122   Fr12=-447   Fr17=-533   Fr20=-465   Fr24=-303
   Time= 121   Fr12=-421   Fr17=-505   Fr20=-443   Fr24=-294
```

EACH TIME STEP IS 0.02 SECONDS



POSITIVE BENDING MOMENT

BENDING MOMENT - RAM #KR426

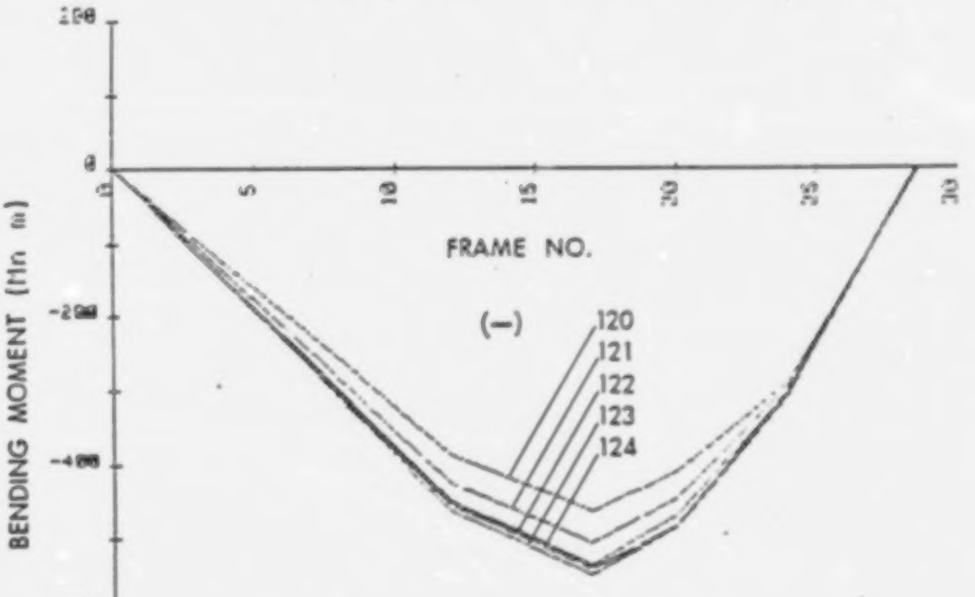


Figure 33 Kigoriak Bending Moment Distribution

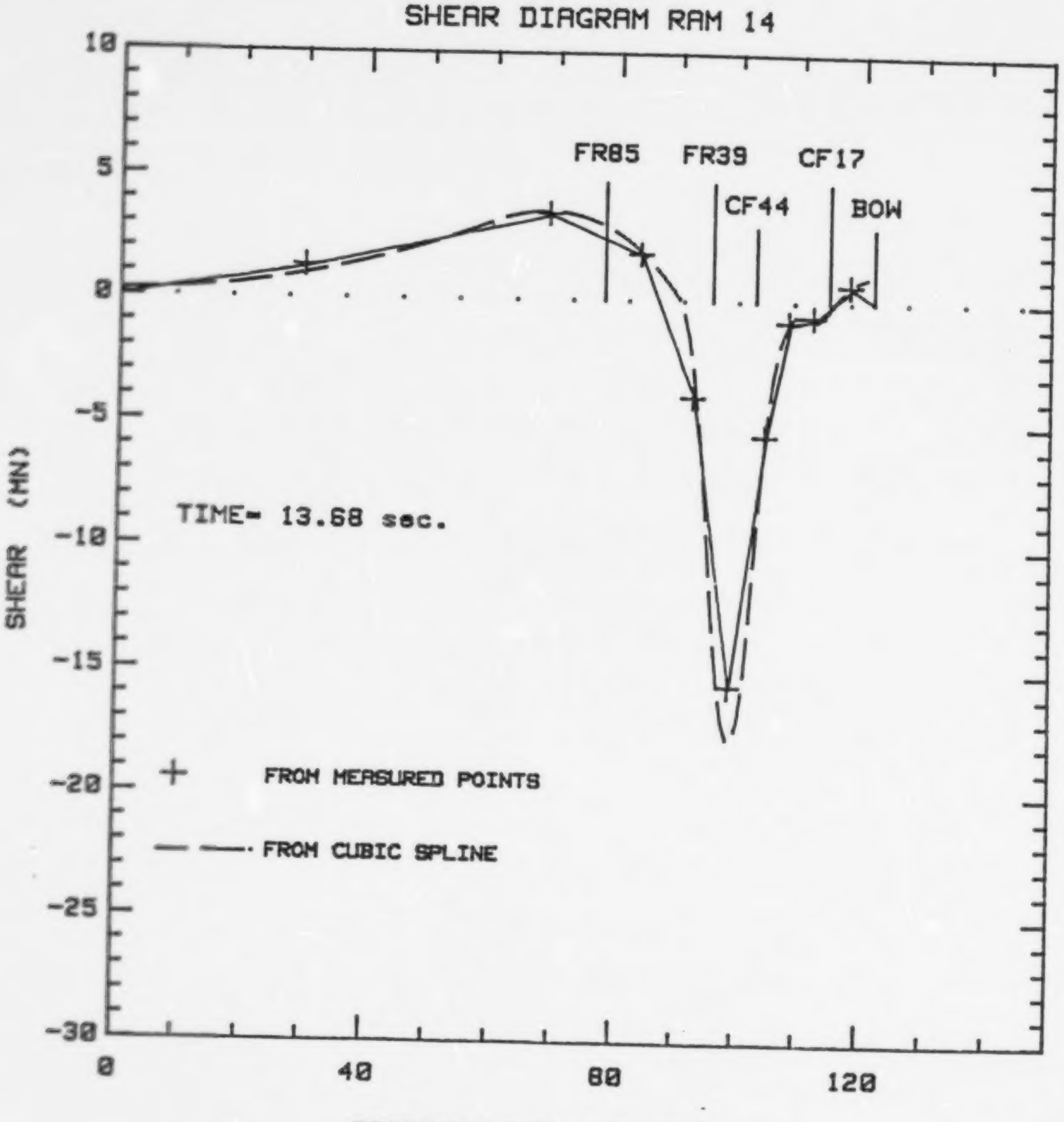


Figure 34 Typical Shear Force Diagram for the Polar Sea

```
KIGORIAK ICE IMPACT TESTS, 1983        PRGM. KR300_501
                                       VERSION 5.3
Test: KR426
Buffer Number: 1

Baseline From Buffer 1  Time 5  to 50

   Time=124.0  12=-15.2  22= 14.9  25= 19.8  27= 22.1  BF= 22.2  POSL=28
   Time=123.0  12=-15.6  22= 14.6  25= 19.7  27= 22.3  BF= 23.3  POSL=28
   Time=122.0  12=-14.6  22= 13.6  25= 19.3  27= 21.9  BF= 24.4  POSL=28
   Time=121.0  12=-12.9  22= 12.5  25= 18.8  27= 21.1  BF= 24.4  POSL=28
```

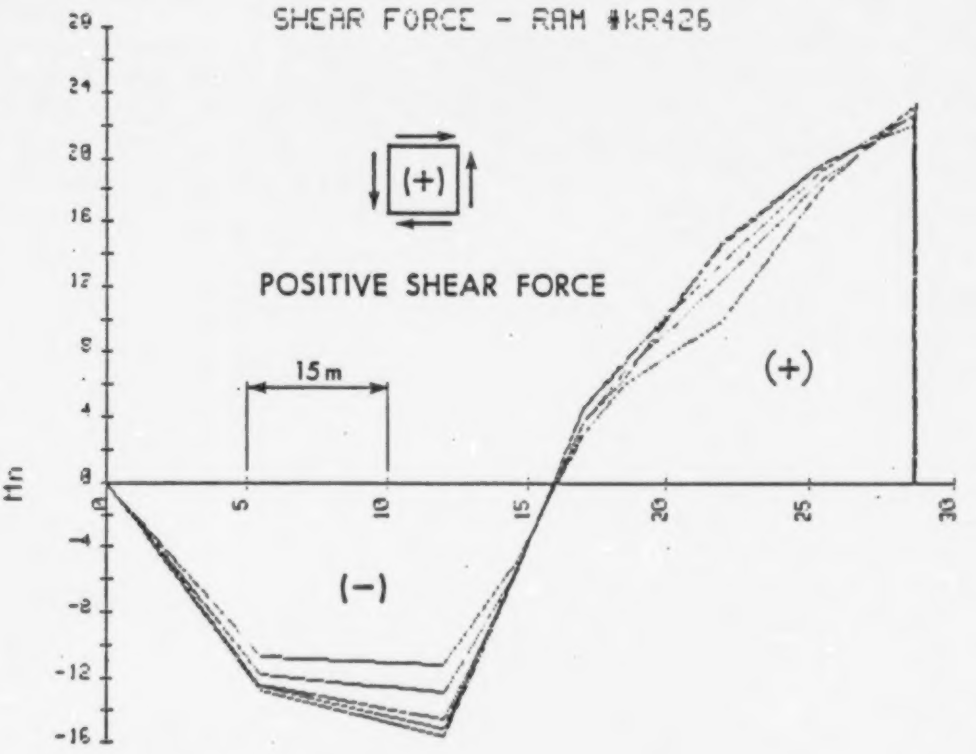


Figure 35 Kigoriak Shear Force Distribution

6. EVALUATION OF GLOBAL LOAD MEASURING SYSTEM

The following significant sources of error are present in the estimation of the global loads:

- Measurement of peak amplitude of bending strain	± 0.6%
- Cross sectional properties (inertia and neutral axis location)	± 10.0%
- Estimation of peak shear force (forward and aft of load)	± 5.0%
- Idealization of bow as a beam	± 5.0%
TOTAL ERROR	**±20.6%**

The vertical force was calculated for two rams using two different techniques. The results were presented in Section 4.1.4. For the two cases considered, the difference was in the order of 5%. This is an estimate of the error associated with the idealization of the bow of the Polar Sea as a beam.

The error associated with the ship speed measurement from the doppler speed log is approximately ± 0.5 knots for the conditions in which the Polar Sea was operated. Speeds less than 2 knots could not be measured.

7. IMPACT ANALYSIS USING "BAFFIN"

During the development of the impact measurement system, some estimate of expected loads were required. These estimates were to be used to exercise the large finite element model developed at ABS, and to compare with actual measurements made during field trials.

Arctec Canada Limited's program "BAFFIN" was employed to make these estimates. "BAFFIN" is a dynamic ship/ice impact program which models head-on impact with infinite or non-infinite ice [18]. Both the ship and the ice are permitted to move and flex.

Figures 36, 37 and 38 show the influence of velocity on vertical force when ramming a square ice edge. One crucial assumption in any ship/ice interaction model is the ice penetration process model. In "BAFFIN", a pressure/area (P/A) formulation is used to calculate pressure (and force) from the total contact area. The P/A equation used in Figures 36, 37, and 38 was:

$$P = 4.3\ A^{-0.5} + .4 \quad (\text{m}^2, \text{MPa})$$

This evaluation was based on full-scale results from the M.V. Arctic trials [19]. It is worth noting that the "beaching" had exceeded the initial impact in all cases. These force values (along with corresponding stress and penetration) were given to ABS to exercise the finite element model.

The reader is now referred to Figure 17 which shows the vertical force during Ram 39. The high initial peak was at first puzzling. Further "BAFFIN" runs were performed to attempt to explain this event. Two alternatives were considered:

1. The pressure/area equation used in "BAFFIN" was incorrect.

or

2. The tacit assumption of a square ice edge was incorrect.

Figure 39 illustrates three P/A curves which were tried in an effort to reproduce Ram 39.

The three equations have the form:

1. $P = 4 - 3\ A^{-0.5} + .4$ (MPa, m^2)
2. $P = 1 - 5\ A^{0.3}$ (MPa, m^2)
3. $P = 2\pi\ \text{SIN}\ (A/10) \quad | > 1$ (MPa, m^2)

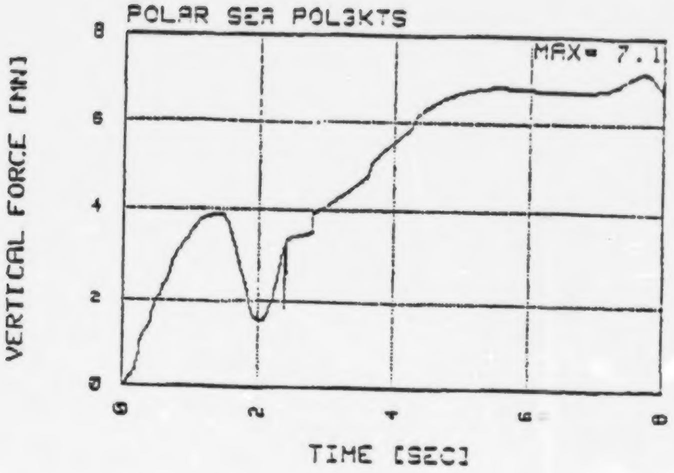


Figure 36 Vertical Force due to 3 Knot Ram
$P = 4.3\ A^{-0.5} + 0.4$

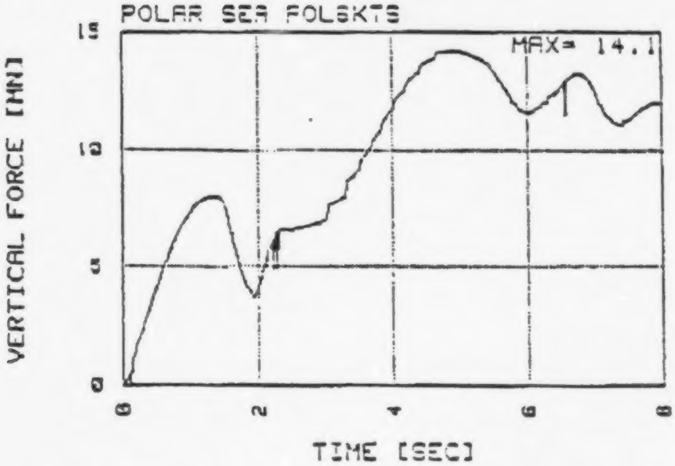


Figure 37 Vertical Force due to 6 Knot Ram
$P = 4.3\ A^{-0.5} + 0.4$

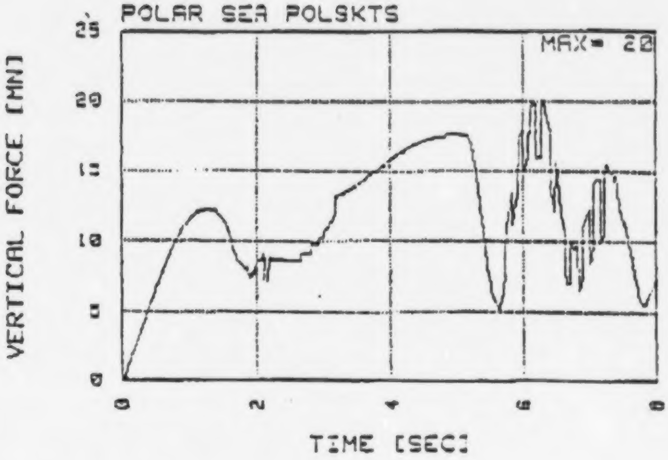


Figure 38 Vertical Force due to 9 Knot Ram
$P = 4.3 A^{-0.5} + 0.4$

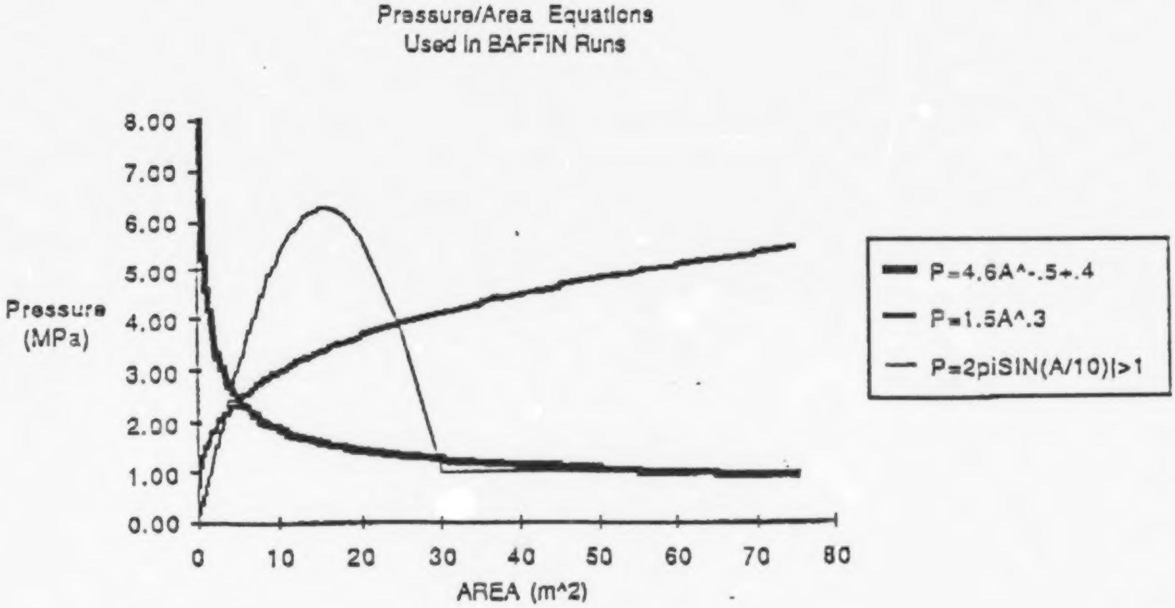


Figure 39 Pressure/Area Relationships Used in "BAFFIN" Runs

Figures 40 and 41 show a 6 kt and a 9 kt ram using equation 3 above. While the initial peak is similar to that obtained in Ram 39 (25 MN), the time to the peak is much longer in the "BAFFIN" run (1 s compared with .5 s for Ram 39). Considering that equation 3 above is very unorthodox, it is most probable that Ram 39 was not against a square edge. Without actual ice edge geometry measurements, it is difficult to compare field measurement with mathematical models. This further emphases the need, when conducting full-scale trials to accurately measure the position of the ship relative to the ice and to measure the edge geometry.

The American Bureau of Shipping analysed the data from the Polar Sea tests using a finite element model (3719 elements) and an analytical model [20]. The recorded data was analysed and compared with forces predicted by the analytical model. The finite element model was executed for various load cases including those loads calculated from the full scale bending stress measurements. The deck bending stresses predicted from the model were compared to the measured stresses for each corresponding load case. A summary of their results is provided in Appendix E. The predicted forces from the analytical model agreed well with rams having a single distinct peak force. The ratio of the calculated peak stress from the finite element model to the measured stress, when a moving load corresponding to Ram 39 was applied, was 1.09. The maximum peak stresses obtained from this model did not agree well with the measured results when loading was applied at one location. It was found that the calculated peak stress was significantly dependent upon the location of the applied load.

Large three dimensional finite element models such as the one constructed by ABS require extensive use of computer time and are costly. The calculation time is further increased when the load must vary in magnitude and location with time (as is the case for an icebreaker during ramming). Investigation of alternative structural finite element modeling of icebreakers, such as two dimensional beam element models, that would reduce the cost and time of analysis but still yield accurate results should be considered.

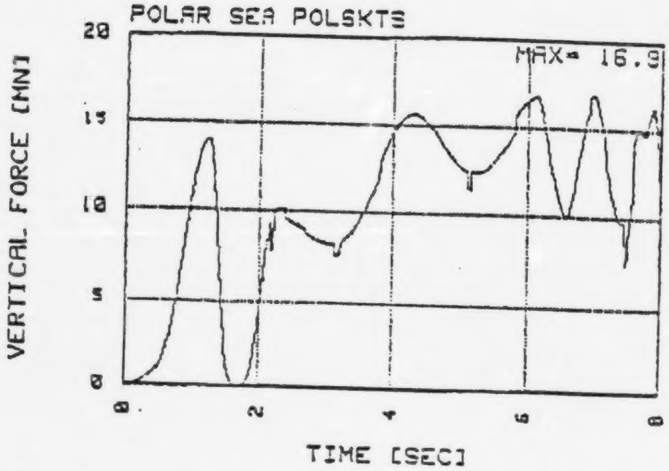


Figure 40 Vertical Force at 6 Knots Ram
P = 2 π SIN (A/10)

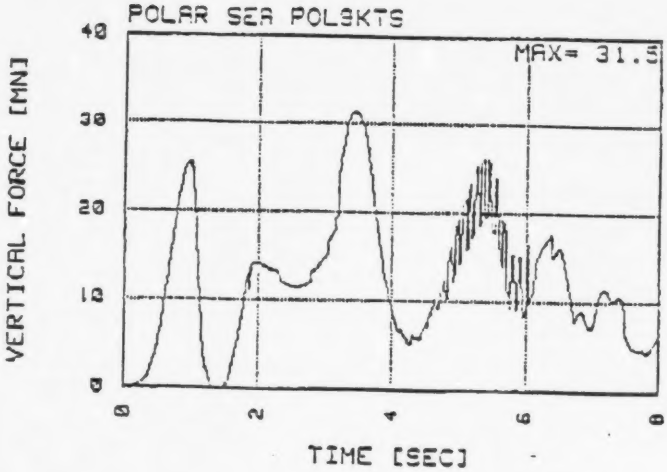


Figure 41 Vertical Force at 9 Knots Ram
P = 2 π SIN (A/10)

8. RESULTS FROM TRANSVERSE COMPRESSION GAUGES

Compression gauges were installed at cant Frame 35 and spaced transversely as shown in Figure 42. The output from these gauges was used to estimate the width of the ice contact zone during impact. Figures 43 to 47 illustrate the time history outputs for these gauges for Ram 14. Figure 48 shows the time history plot of the transverse acceleration of the vessel as measured by the accelerometer in the bow. Analysis of these figures results in the following observations:

1. The compression of the ice against the port side and starboard sides of the hull are out of phase by approximately one second. The peak compressive strain at location 11S occurs at 13.8 seconds, and that from the opposite side (location 11P) occurs at 15 seconds. The vessel is rolling from starboard to port in this ramming event as illustrated in Figure 48. This time history plot indicates is an acceleration of approximately 0.1 g's towards the starboard side from 13.5 to 13.8 seconds corresponding to the increase in compressive strain at location 10S.

2. There is negligible compressive strain measured from the gauge at the highest level, location 9P, illustrated in Figure 48. Therefore, there is no ice contact at this level. The extent of the transverse ice contact zone can be estimated to be from gauge location 10S to 10P or 1.48 m as shown in Figure 42.

The analysis of the output from these gauges provides qualitative and quantitative information on the ice-ship interaction process and therefore warrants further investigation.

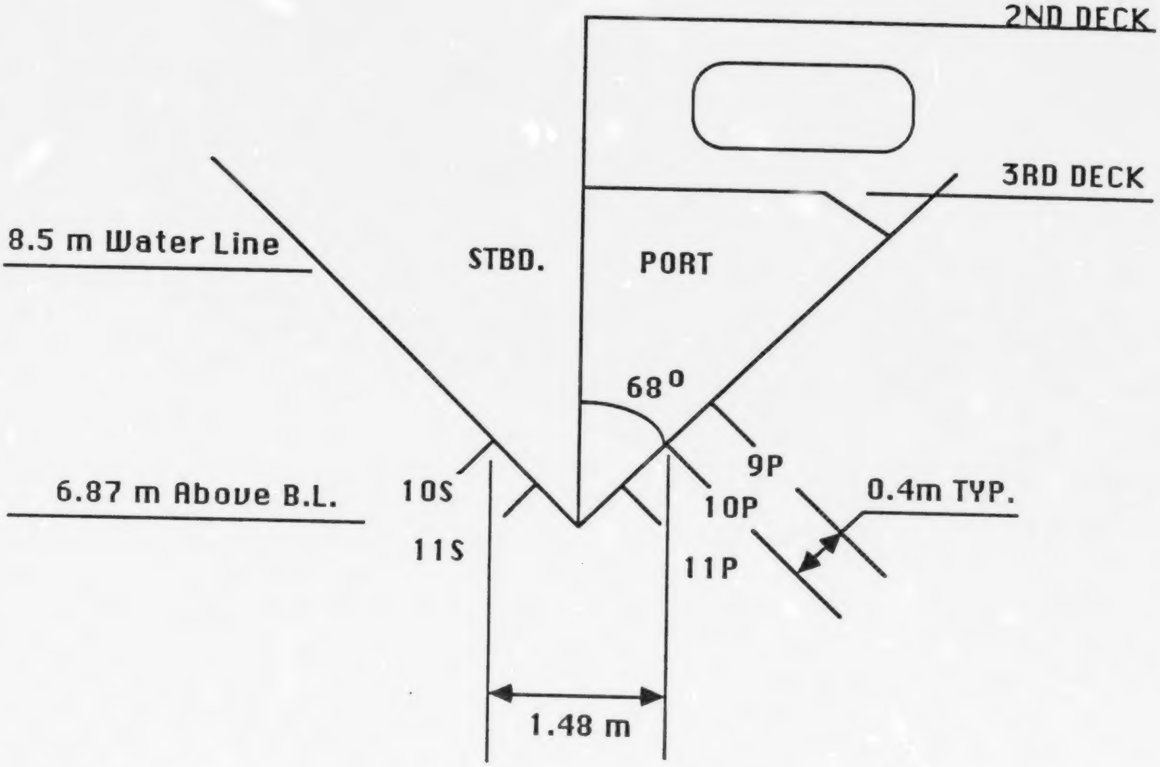
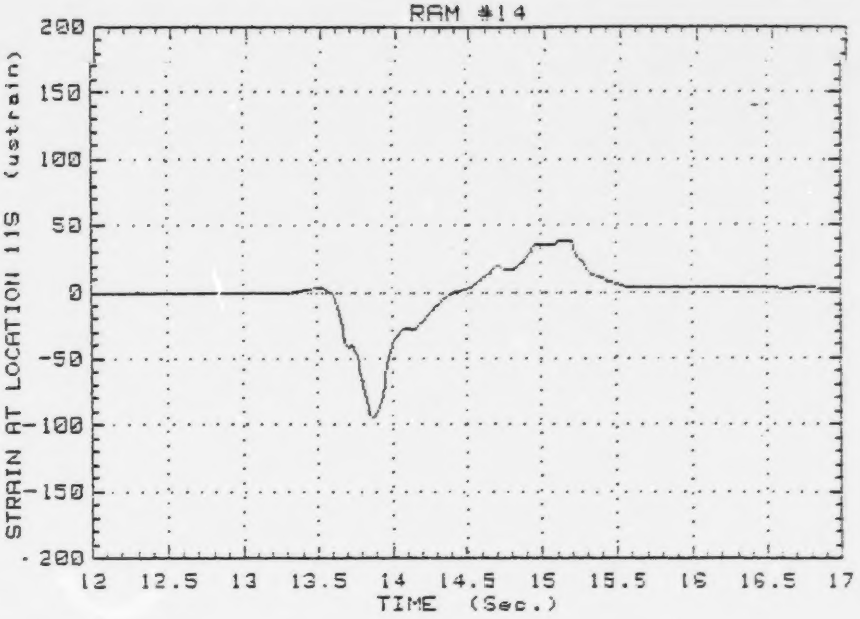

2ND DECK
3RD DECK
8.5 m Water Line
STBD.
PORT
68°
6.87 m Above B.L.
10S
11S
9P
10P
11P
0.4m TYP.
1.48 m

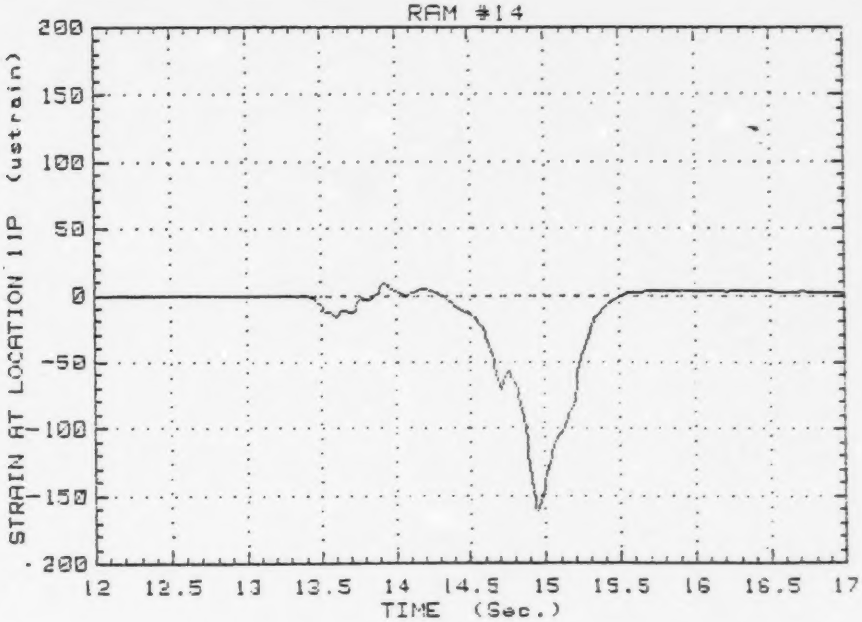
Figure 42:
Transverse Compression Gauges on Cant Frame 35



Tension

Compression

Figure 43 Strain Time History at Location 11S



Tension

Compression

Figure 44 Strain Time History at Location 11P

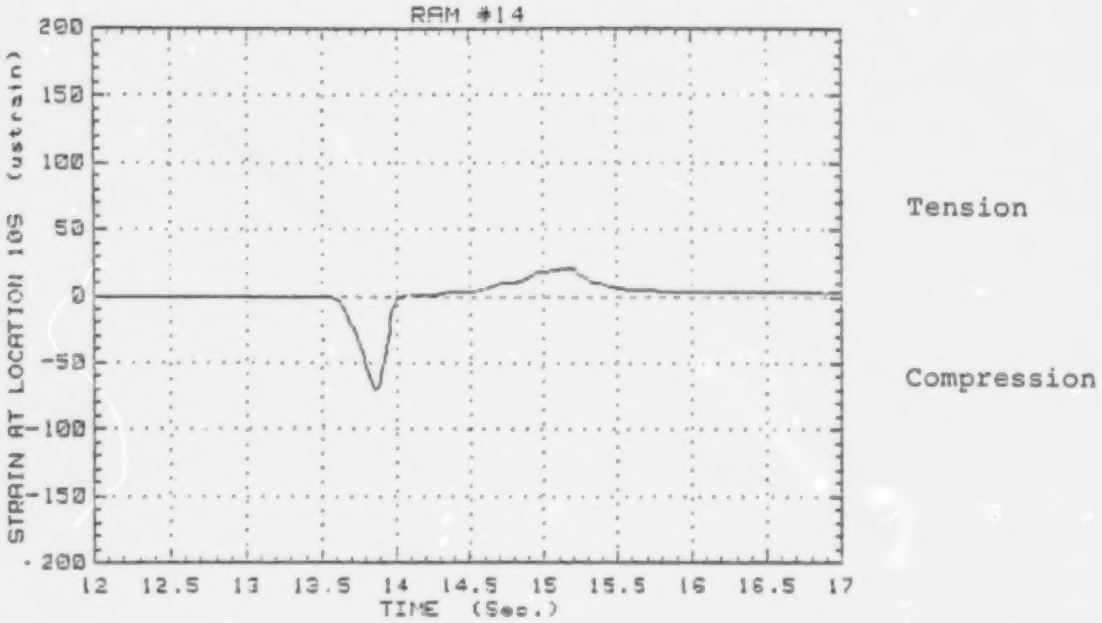


Figure 45 Strain Time History at Location 10S

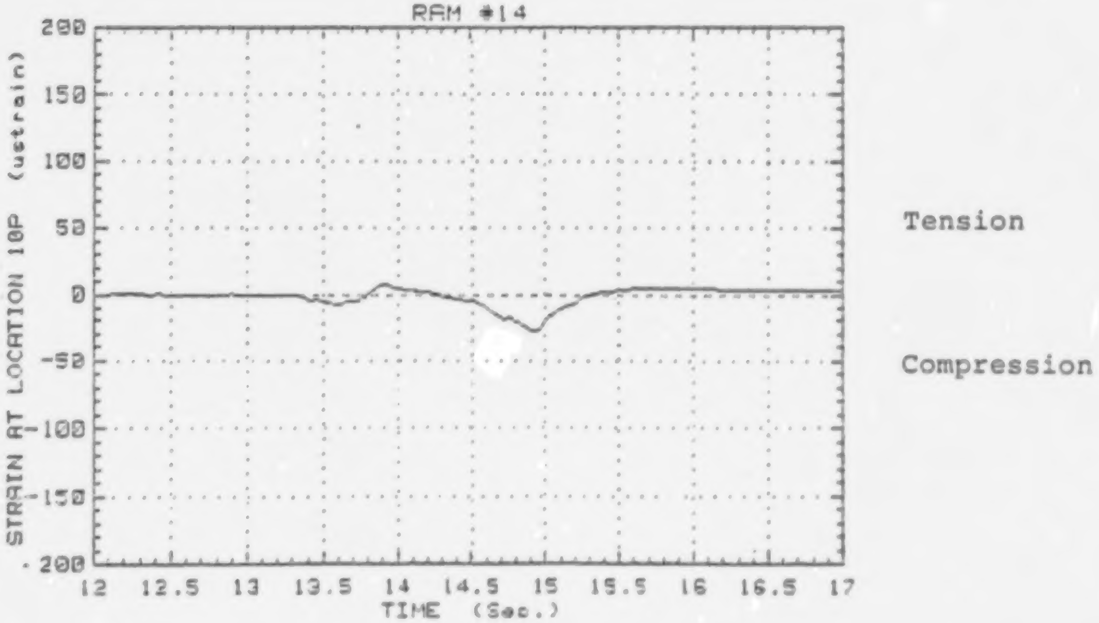


Figure 46 Strain Time History at Location 10P

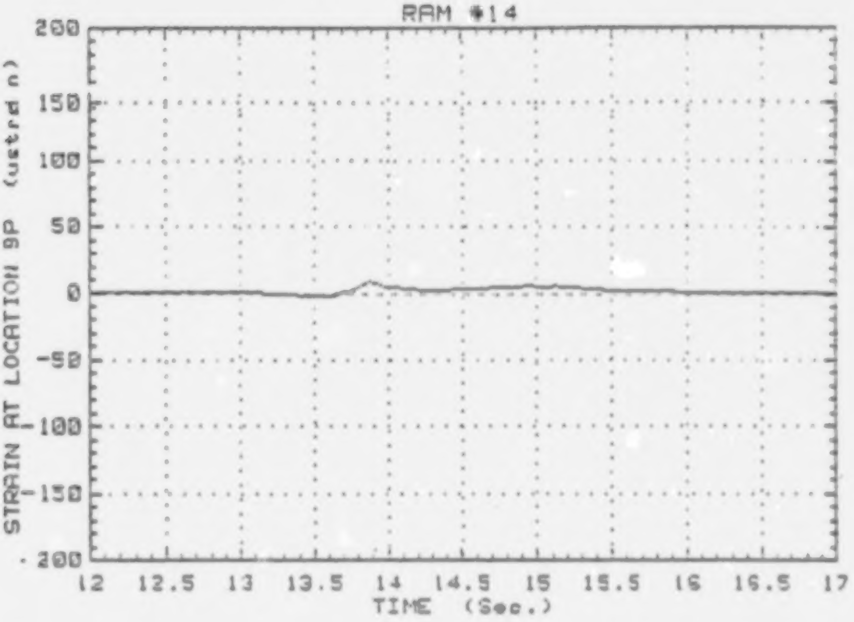


Figure 47 Strain Time History at Location 9P

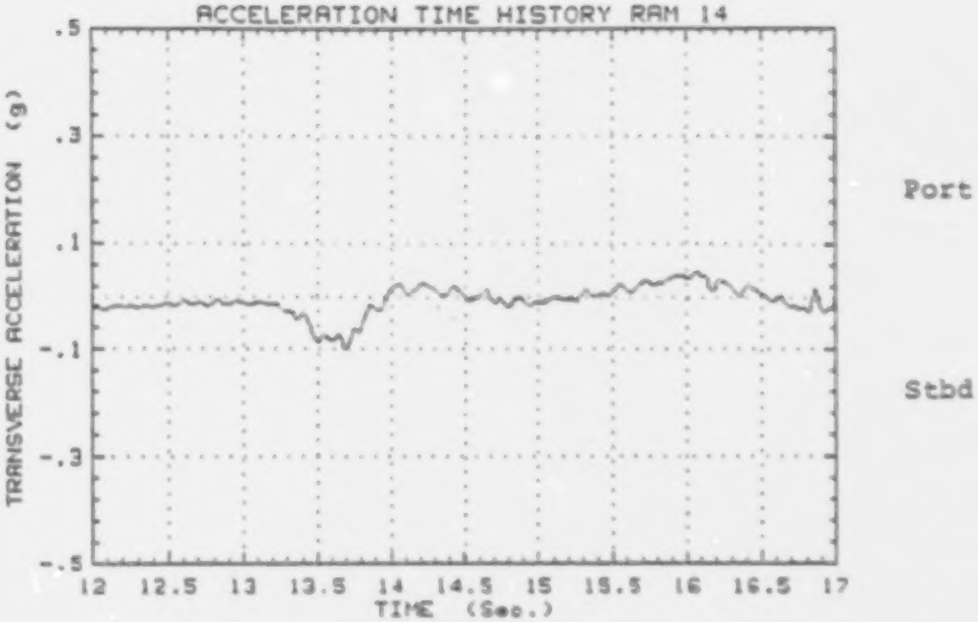


Figure 48 Transverse Acceleration Time History Ram 14

9. CONCLUSIONS

The following is a list of the conclusions from this work:

1. The global load measuring system is an excellent method for determining the response and vertical ice force of an icebreaker during ramming.
2. The idealization of the Polar Sea as a beam in plane bending during ramming provided a good estimate of the vertical bow force.
3. The use of bending gauges provided an excellent estimate of the longitudinal shear and bending moment distributions, for relatively few gauges.
4. The stem bar compression gauges provided an estimate of the impact velocity of the Polar Sea, as well as the centre of location of the ice force.
5. The ice force on the Polar Sea should not be treated as a point load.
6. The super-structure is effective in bending and should not be ignored in design calculations.
7. The maximum bending stress of 41.9 MPa was measured on the 01 deck at the forward end of the superstructure (Frame 39).
8. The loading rate was measured to be as high as 50 MN/s, compared to the Kigoriak's loading rate of 150 MN/s [13].
9. The vessel did not "rebound" after the first impact with the ice as was observed in the Kigoriak tests [13].
10. The impact duration (length of time of first peak) is approximately 0.8 seconds for the Polar Sea. This compares with 0.48 seconds for the Kigoriak.
11. The dominant response of the vessel was at the first mode of vibration (3 Hz).
12. The maximum calculated vertical bow force during ramming was 24.97 MN.
13. The flare angle of the bow should be incorporated in analytical and semi-empirical equations for the estimation of the global bow force.
14. The data collected during these tests provides an excellent understanding of the response of the Polar Sea to ramming heavy ice features. It also provides excellent data for the development and testing of ship-ice interaction models.
15. This further emphases the need, when conducting full-scale trials to accurately measure the position of the ship relative to the ice and to measure the ice edge geometry.

10. RECOMMENDATIONS

It is recommended that:

1. Further analysis be done on the unsymmetric ramming tests. (e.g., estimate of the transverse force).
2. Further analysis of the stem bar gauges be conducted (e.g., ice contact length vs. time, distribution of stresses along the stem bar).
3. Numerical analysis of the effect of the flare angle of the bow has on the force/velocity relationship.

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APPENDIX A

STATEMENT OF WORK

Reference Table for Work Statement

Task	Reference
A1.3 Software Development	Appendix D and Section 2
A1.4 Instrumentation System	Section 2
A1.5 Conduct Impact Tests	Section 3 and Appendix C
A1.6 Analysis of Load Test Data	Section 4

Appendix 'A'

1923

WORK STATEMENT

US POLAR CLASS PROGRAM 85/86

1. Introduction

Continuing Canadian Participation in the joint program managed by the US Maritime Administration and supported by several US government agencies and oil companies, is embodied in this project. About one year of R&D activity related to the US Coast Guard "Polar" class icebreaker comprises three segments, as follows:

a) A Summer (1985) expedition to multi-year polar ice in the Alaskan Beaufort Sea, to conduct global ice force measurements, etc. This is the subject of Arctic Canada Ltd. proposal no 1923AP.1 "Polar Class Deployment, Arctic Summer 1985, Measurement of Global Ice Impact Loads" dated May 1985.

b) Impact tests with glacial fragments, to be carried out in Columbia Bay, off Prince William Sound, Alaska. This is the subject of Arctec Canada Ltd. proposal ACL 1923BP-2, AEl 1115P-1 "Measurement of Glacial Ice Loads on Instrumented Bow Panel Aboard USCGC "Polar Sea" in Columbia Bay, Alaska, October 1985" dated May 1985.

c) Measurement of manoeuvring parameters during tests to be conducted in conjunction with the January 1986 annual break-in to McMurdo Sound, Antarctica. This is the subject of Arctec Canada Ltd. proposal No 1923 CP "Proposal to conduct Manoeuvering tests Aboard US Polar Class in Antarctic 1986" dated 31 May 1985.

This work statement is based on the above noted proposals, and although the work is appropriately contained in one contract, it is intended that reporting and accounting be kept separate. Work defined herein is the Transport Canada contribution to a joint program, it will be carried out in cooperation with a US Contractor executing related tasks under contract to the US Maritime Administration.

2. Modal Objective

To develop all aspects of technology required to establish safe and efficient year-round navigation capability in Arctic Waters as required by Canada.

3. Modal Sub-objective

To provide a scientific basis for design or operating criteria applicable to regulations regarding navigation in Canadian Arctic waters.

4. Project objective

The objectives of this project are:

a) To measure, record and analyse global ice-hull interaction forces in multi-year ice.

b) To measure local hull forces due to impact with fragments of glacial ice to compare with effects of other ice types.

c) To measure ice manoeuvering performance in level ice and use the data to refine and calibrate an ice manoeuvering model.

5. Detailed statement of work

The work constituting this project shall include the following elements and shall be consistent with the relevant segments of the Arctec Canada Ltd. proposals identified above. (Referred to collectively as the Proposals and individually as the Proposal, indicating the one of which the sobject relates to that under consideration) Items specified below in relation to the several tasks, are to be read in conjunction with the task definitions in the respective Proposals.

5.1 Work Plan

Develop a detailed work plan and budget for each of the three main tasks, including activity schedule, cash flow projection, project management control and documentation procedures, within four weeks of the effective commencement date of each task. Sequential activities are to be shown on a network diagram and milestone points at which the draft summaries of working papers described in paragraph 8.2 will be made available. The plan is to be updated as work progresses and plans are further developed or modified. Expense summaries reported in progress reports are to be reconciled with invoices.

5.2 State-of-the-Art Bibliography

Being well informed as to the subject matter of this project, the Contrator is to provide a bibliography listing of works, published or not, known to him and relevant to the project. Those which are particularly useful are to be so indicated, and an abstract supplied. Where the proprietary nature of an item is felt to preclude its listing as above, a reduced method of indicating its existence may be employed in order to avoid any unethical disclosure.

In addition to the above, a brief literature survey is to be carried out to discover and evaluate any work of which the contractor is not aware; any information which could influence the conduct of this project is to be promptly notified to the Scientific Authority.

5.3 Tasks

Tasks outlined in the proposals are modified and further defined as outlined below; if there is any inconsistency, this work statement is to take precedence.

5.4 Global Impact Loads Task Group A

Global impact load testing is to be carried out with a USCG "Polar" Class icebreaker in mostly multi-year ice in the Alaskan Beaufort Sea in October 1985. The following task prefixed"A" refer to task numbers used in the Arctec Proposal on this subject.

5.4.1 Planning - Task A1.1

Deleted * Prepare program plans and test plans, attend planning meetings, prepare test schedules and cash projections for the execution of a test program to measure global loads aboard the USCGC POLAR SEA in October 1985.

Update plans, schedules, projections etc as project progresses; finalize detail plan and procedures for each list, also data analysis procedures and outline of final report.

5.4.2 Finite Element Model - Task A1.2

Deleted * The contractor will execute a ship/ice interaction program and determine the peak bow loading expected on the vessel during impacts with multi-year ice. He will act as specialist consultant to ABS in the preparation of a Finite Element model of the vessel, whose program is to assist in locating and interpreting gauge data. The consultation wil take the form of approval of the model configuration, meshing pattern, definition of the loading and analysis of the results.

5.4.3 Software Development - Task A1.3

Deleted * The contractor will obtain from CCG software asssociated with the measurement of Global Loads on KIGORIAK and will modify this to be suitable for use on POLAR STAR. The modified program is to be documented and validated.

5.4.4 Instrumentation System - Task A1.4

Deleted * Design of the instrumentation system is to be carried out, components selected, purchase orders and installation diagram etc. prepared in readiness for actual installation etc.

Install the instrumentation system as proposed; carry out checking and calibration procedures (internal) to verify effective functioning, prior to testing. Steps outlined in section 8.6 may be foreshortened as required by time constraints.

* Items marked Deleted * were included in an amemdment to a previous contract, they are shown here for completeness only, work is not to be repeated nor charged again.

5.4.5 Conduct impact tests - Task A1.5

The contractor is to participate in the approximately 12 day testing program scheduled for October 1985 in the Alaskan Beaufort Sea, in conjunction with the U.S. test team. "Global Load" data collection is the primary objective, along with sufficient environmental data to clearly define ice configuration and quality in the immediate vicinity of the impact, and to obtain a record of the after-impact condition of the ice (ie. nature, shape, dimensions, etc. of the indentation and of the displaced ice).

An "after action" report is to be submitted on completion of the test period, indicating the quantity and quality of data, general comments on the tests, etc.

5.4.6 Analysis of Load Test Data - Task A1.6

In addition to mechanized computation of ice loads, bending moments, etc. examples of representative and of some exceptional cases are to be examined at critical stages of the computation process, such as any extrapolation processes, to verify that intermediate results are consistent with expectation and other data that may be available. The examination is to be appropriately displayed; for instance, measured bending stresses should be plotted on a graph showing stresses predicted from the calculated total force, etc.

Any dubious or contentious areas of the prior Kogoriak analysis on which this work in based, are to be re-examined and discussed in the light of results obtained.

As indicated by the modal sub-objective, the analysis is as far as possible to provide a basis for establishing design and regulatory criteria.

5.4.7 Reporting

Reporting is to include definition and explanation of theories, hypotheses, assumption, calculation methods, etc. as outlined in section 8 "General Instruction".

5.6 Ramming Cycle Study - Task A 2

During ramming operations, observations of ice conditions and ram parameters are to be recorded by a bridge observer, and subsequently reported with a brief analysis.

5.7 Local Loads - Task A3

As opportunity permits, the hull load measurement panel, having been prepared for use in accordance with the "B" series or tasks, is to be put into operation and data collected in similar format to that used on prior occasions. The data collected is to be added to the existing data base.

To the extent possible, some impacts are to be carried out on isolated multi-year and first year fragments, and ice samples collected, in the same manner as intended for glacial ice fragments. Data from these impacts is to be identified for subsequent comparison with glacial ice impacts.

5.8 Environmental Data collection - Task A4

The contractor is to ensure that environmental data collected includes definition of quantities, qualities and characteristics of the ice involved in the various tasks defined herein, to a degree adequate for effictive analysis of results and extrapolation to other ice types.

Some direct physical measurement of representative of ice strength is desirable, if feasible.

5.9 Glacial Ice Loads - Task Group B

Glacial Ice Load testing is to be carried out with a USCG "Polar" class icebreaker with glacial fragments in Columbia Bay, Alaska, in October 1985. The instrumented hull panel of USCGC "Polar Sea" will be used in the same manner as previously.

The following tasks, prefixed "B" refer to task numbers used in the Arctec proposal on this subject.

5.9.1 Planning-Task B1.1

Prepare plans, schedules, etc. update them as the project progresses.

5.9.2 Instrumentation-Task B.2

Survey and repair as required the elements of the system already on board, install additional strain gauges as feasible and as considered appropriate for the special nature of this test series. Re-install parts of the system removed from the previous tests and not already re-installed for global load tests. Carry out a complete system check to verify that all elements are working properly.

5.9.3 Prepare Ice Data Collection Equipment - Task B.3

Assemble and prepare equipment in accordance with test plans as proposed and as specified elsewhere in this work statement.

5.9.4 Carry Out Glacial Ice Impact - Task B.4

Carry out testing as proposed, and in accordance with paragraph 8.0. Rigid body ship response motions, and initial conditions of pitch etc. at time of impact are to be recorded if possible.

5.9.5 Data Reduction and Analysis - Task B.5

Reduce and analyse ice force data in accordance with procedures established for this load panel. Methods of assessing ice properties are to be fully explained, and the method of comparing glacial ice impacts with those with other types of ice.

5.9.6 Reporting - Task B.6

The report is to be as proposed and in accordance with TP929 and other requirement of this work statement.

Distribution of the report will be restricted in accordance with appendix "C" to this contract; the date on which the restriction expires is to be recorded in the appropriate block of the RDF page.

5.10 Antarctic Manoeuvering Tests - Task C

Manoeuvering tasks are to be carried out in level ice in McMurdo USCG Sound, Antarctica, with a "Polar" class icebreaker in conjunction with the January 1985 break-in.

The following tasks, prefixed "C" refer to task numbers used in the Arctec Proposal on this subject.

5.10.1 Planning - Task C1

Test plans are to be developed in conjunction with design of the instrumentation system, as outlined in section 8.

5.10.2 Instrumentation System - Task C2

The project officer is to be kept informed during the development of the design of the instrumentation system, approximately as outlined in section 8.

Instrumentation is expected to be generally similar to that used during January 1985 manoeuvering test, but the following are to be investigated:

a) Use of radar for ships track information, in place of the transponder system;

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b) Recording wind speed and direction;

c) A record of the occurrence of propeller/ice interaction, to assess the effect on it of turning.

d) Provision of camera equipment to obtain a record of hull/ice interaction processes during turns, using a helicopter if available.

5.10.3 Carry out Manoeuvering Test - Task C3

It is unlikely that a Transport Canada representative will be available for these tests, other arrangements should be made to carry out those tasks previously assigned to him.

If possible a visual record, from a helicpter, of hull/ice interaction along the full length the waterline (where there is contact) during representative turns, on both the inside and outside of the turn. Comparative records with the ship upright and heeled, are desired.

5.10.4 Analysis - Task C4

A plan for analysis of the data is to be developed and reviewed by the project officer prior to its implementation. Assessment agains the new data, of the effectiveness of previously developed manoeuvering model is to be included.

5.10.5 Reporting - Task C5

Reporting is to be as proposed and as specified in general terms in this Work Statement. Addition charges for draft reports will only be considered if changes beyond the scope of this contract are requested by TDC.

5.11 Preparation of Final Report and Progress Reports

Section 10 "Reporting Requirements" also refers; minimum monthly reports covering the items specified will be required, but reports of technical progress including terms specified under item 8 "General Instructions", may be on a quarterly or milestone basis.

6. Project administration

The Executive Director, Transportation Development Centre (TDC) will appoint a Project Officer to manage the project on behalf of TDC. A committee may be convened at the invitation of TDC to counsel the Project Officer, to monitor progress and comment as necessary on the envisaged work to be done. A Project Monitor may also be contracted by TDC to assist the TDC Project Officer. Contract administration will be provided by Supply and Services Canada (DSS).

7. Role of other parties

The US Maritime Administration (MarAd) Arctic Program Manager is Mr. F. Seibold, and initial contacts with other US authorities involved in the project are to be arranged through him via the TDC Project Officer, Mr. I.M. Bayly. Copies of all US contact correspondence are to be passed to the TDC Project Officer for information.

Arctec Inc. (USA) is the MarAd contractor for technical input and coordination of US bodies involved in the overall project. Direct communication and cooperation between the two affiliated companies, is expected but the TDC project officer is to be informed of significant arrangements etc. which are made.

The US Coast Guard are involved as owners and operators of the trial ship as well as participating in scientific studies. Permission for use of drawings, etc. related to the ship, is to be obtained from them, even if available through Arctec Inc. approval for installation of instrumentation will also be required.

8. General instructions

8.1 In order that the data will be useful for future analysis, high standards of completeness, accuracy and definition of test records are an essential feature of this project.

8.2 Copies of draft or summaries of working papers including development of hypotheses, analyses, calculations, test plans, etc., covering segments of the work are to be made available to the project officer as they are developed or applied as work progresses; these may eventually form segments of the final report. Tasks as defined in the activity schedule will not be considered complete until working paper drafts are received.

8.3 Theories, assumptions, calculation methods, etc., applicable to this study are to be outlined and explained in the report, or in appendices, making reference to standard texts, technical papers, and other published work as appropriate. Complete listings of computer programs used are to be provided, with sufficient explanation to facilitate understanding by someone aquainted with the language; inputs and outputs are to be fully defined and explained. Special arrangements may be made concerning large, publicly available programs, or material considered to be of proprietary nature. Any intention to use proprietary data is to be notified in advance, failure to achieve agreement could preclude its use for this contract.

8.4 Calibration procedures and results obtained are to be reported for sensors, recorders, and other components of instrumentation and recording systems, also the systems or subsystems as complete entities. Calibrations are to include response to dynamic and harmonic excitations. Advance notification is to be given, so that they can be witnessed by the Scientific Authority.

8.5 Where reference is made to works which are unpublished or difficult to obtain, complete and fully legible copies will be made available at the same time as the draft working papers in which the relevant references are made.

8.6 Design of Instrumentation System

8.6.1 Design of the instrumentation system or of any change to it is to be fully reported at stages of its developments, such as:

a) Preliminary designs, with alternative system or of any configurations and various probable choices of equipment, calibration methods, etc. Characteristics of candidate items of equipment are to be reported, together with approximate costs.

b) Draft final design, with more detailed information concerning selected types of equipment, calibration, and the installation of sensors.

c) Final design and specification for purchase, installation and calibration. After installation this may be amended to provide a record for para. 8.10.4.

Each stage is to be approved by the Scientific Authority prior to proceeding, to more than a limited extent (Limit to be agreed).

8.7 Installation of Instrumentation and Calibration

Purchase or rental, delivery, installation and removal of the instruments which, under this contract are contributed to this project, will be the responsibility of the Contractor, in association with US Authorities and contractor.

8.7.1 High quality materials, equipment and methods are to be used in order to contribute to reliable operation of the system during the trials.

8.7.2 Coordination with other instrumentation and ship activities will be arranged by Arctec Canada Ltd. through their U.S. associates. The Scientific Authority is to be kept informed and notified promptly of any problems which appear likely to lead to delay or failure to complete a task properly.

8.7.3 Arctec Canada Ltd. is responsible for delivery of Canadian contributed equipment for this project to the ship, for its removal and return to its owners and for any effort required as a result of instrumentation for the project, to restore the ship, to the satisfaction of her Captain, to approximately the same condition as before.

8.8 Preparation of Test Plan

Test plans are to be outlined as instrumentation system is designed.

8.9 Performance of Full Scale Tests

Arctec Canada Ltd. will provide an experienced engineer to be on board the ship during the period of the trials, to be responsible in cooperation with others for the effective implementation of all aspects of this most important part of the program, including:

8.9.1 Planning and arranging final details of the trial program or changes to it as may be appropriate to the circumstances, and coordinating with the ship's Captain, officers, and other US authorities involved, as well as with Arctec Inc.

8.9.2 Carry out or arrange for carrying out of all functions pertaining to operation, maintenance, and calibration of the instrumentation system installed for this project. On board calibration techniques and measurements are to be recorded and reported.

8.9.3 Keep TDC project officer on board for the trial, informed of all plans and significant events.

8.9.4 An "after action" report is to be produced on completion of the trials. This is to indicate the quantity and quality of data recorded and general comments on trials, etc.

8.10 Data Cataloguing, Reduction and Analysis

8.10.1 Raw data is to be preserved and catalogued with a clear and complete explanation as to how all or any part of it may be accessed for review or re-examination. Cross reference keys are to be provided or identified, and explained so that separate records of the same event may be correlated readily with each other.

8.10.2 Data reduction procedures are to be fully explained, with sample calculations and full particulars (by reference if appropriate) of any computer programs or processes used. Where appropriate, records of reduced data are to be preserved and catalogue as above.

8.10.3 A representative number of typical segments of data involving incidents of interest, including but not only those which are selected for analysis, are to be presented in the report with pictures and diagrams, etc., as appropriate and an explanation to give a clear understanding of what is recorded, how, and the behaviour of each parameter during the event.

8.10.4 Information as to the instrumentation used to measure and record the data is to be reported, including its nominal accuracy, calibration procedures and resuls, with a sample calculation of results. Where specific information as to the accuracy of measurement is not available, estimates are to be made and explained.

8.10.5 Full particulars of analyses are to be reported: analysis methods are to be fully explained, with supporting rationale and sample calculations. Existing methods are to be critically reviewed and updated if appropriate.

8.10.6 Errors which are inherent in the accuracy and precision of measuring system are to be defined and evaluated, with and estimate if specific information is not available. Errors which may be introduced in conjunction with analytical or computational methods or approximations used in reduction and analysis of data are similarly to be reported. A simple type of calculation or estimate of the cumulative effect of errors (as noted above or otherwise) on numerical results is to be made and reported as a tolerance on the results.

8.11 Software

Computer programs considered suitable for future use are to be adequately documented with explanations and instructions, etc. to enable them to be used readily by others having appropriate competence. Programs are to be provided in a mutually convenient form, such as on tape, floppy disc, etc., as well as in the form of a complete listing. IBM Standard Interchange Format is to be used unless an alternate is approved.

9. Project Control

Budgets for each elements of the project will be prepared at the start of the project and monitored regularly to ensure resources available are compatible with estimates to complete the work. CPM, PERT, or equivalent responsibility assignment and scheduling methods are to be used as appropriate.

10. Reporting requirements

10.1 Progress Reports

To facilitate the management of the project, a minimum of three copies (or as mutually agreed upon), of the progress reports shall be submitted on a monthly basis to the TDC Project Officer, with a copy to the DSS Science Procurement Manager. These reports shall be short and concise.

10.1.1 A list of all persons working on the project and their functions during the reporting period, in relation to each task.

10.1.2 Current status of work, containing an estimate of the percentage of work completed, the percentage of time elapsed, and a clear statement as to whether the project will on will not be completed within the established schedule and the agreed financial limitation.

DSS form DSS-MAS 9143-3 "Contract Plan and Report Form" is to be updated and submitted, or equivalent print-outs from the contractor own management system. Cost figures are to be reconciled, at least approximately, with the most recent (or imminently pending) invoice.

10.1.3 Work accomplished since the period last reported, related to tasks and amounts involved.

10.1.4 Problem areas, if any.

10.1.5 Work to be addressed and expected to be achieved in the coming months.

10.1.6 Any action required by TDC.

10.1.7 Contact made with outside agencies or companies, or major visits planned in connection with the project.

10.1.8 Other important information deemed to be appropriate.

10.2 Publication Standards

10.2.1 All reports with the exception of progress reports shall be prepared in accordance with the "TDC Publication Standards for Contractors (TP 929)" the latest issue to be provided to the contractor by the DSS Science Procurement Manager at the contract negotiation stage.

10.2.2 A summary report shall be prepared in both official languages for all final reports whose main content, excluding appendices, figures, tables, etc., exceeds 25 pages. If unable to provide a summary report in the other official language, TDC shall make alternative arrangements.

10.2.3 A bilingual Report Documentation Form shall be included in every report as specified in TP 929, with the page format supplied by TDC.

10.2.4 Covers for the summary report shall be provided by the TDC Project Officer as soon as the draft of the report has been approved.

10.2.5 S.I. metric units shall be used in all reports. (Unless special exception is warranted).

10.3 Delivery Schedule of Reports

10.3.1 A target schedule for submission and approval is as follows:

a) 6 copies each of draft summary reports and Report Documentation Form and draft final report 4 weeks after completion of the other work on the project.

b) TDC comments on draft reports to contractor 8 weeks after receipt, or by arrangement.

c) 100 copies of summary reports (60 English / 40 French) 4 weeks after receipt of TDC's comments.

d) 25 copies of final report (in contractor's working language) 4 weeks after receipt of TDC's comments. Additional copies are to be supplied to meet requirements for distribution to U.S. participants; number required are to be ascertained.

e) Additonal copies of final report and English summary as required for US distribution.

10.3.2 For control purposes, all reports, except progress reports, shall be delivered to:

Supervisor, Records Office
Transportation Development Centre
Transport Canada
Complexe Guy Favreau
200 Dorchester Blvd. West
Suite 601, West Tower
Montreal, Quebec
H2Z 1X4

The Records Office will ensure that copies are forwarded to the Project Officer.

APPENDIX B

FIELD NOTES / CALIBRATION NOTES / SENSOR SPECIFICATIONS
LIST OF DATA PRODUCTS
CROSS REFERENCE TABLE OF SENSORS

LIST OF DATA PRODUCTS

1. Analysis Disk - Contains program "CALC1" used for analysing data Configuration files also on this disk.

2. Results Disk - Contains the following maximum values as well as the location and time of occurrence:

    - Bow Force
    - Bending Moment
    - Bending Stress
    - Impact Velocity

3. Data Tape - Contains unprocessed data for all 40 rams.

TABLE B1

POLAR SEA IMPACT TESTS FALL 1985

CONFIGURATION FILE: ENGUNIT1
FOR RAM 1 AND RAM 2

SENSOR SPECIFICATIONS

CHAN#	CHAN ID	CALIB	G. F.	EXIT.	BRIDGE	UNITS
1	C_C24	2.487E-6	2.01	10.00	2.00	strain
2	C_C26	2.487E-6	2.01	10.00	2.00	strain
3	C_C29	2.487E-6	2.01	10.00	2.00	strain
4	C_C30	2.487E-6	2.01	10.00	2.00	strain
5	C_C32	2.487E-6	2.01	10.00	2.00	strain
6	C_C34	2.487E-6	2.01	10.00	2.00	strain
7	C_C36	2.487E-6	2.01	10.00	2.00	strain
8	C_C38	2.487E-6	2.01	10.00	2.00	strain
9	S_C27	2.487E-6	2.01	10.00	2.00	strain
10	S_C35	2.487E-6	2.01	10.00	2.00	strain
11	B3_C35C	2.487E-6	2.01	10.00	2.00	strain
12	B3_C44C	2.487E-6	2.01	10.00	2.00	strain
13	B2_C17C	2.487E-6	2.01	10.00	2.00	strain
14	C_C20	2.487E-6	2.01	10.00	2.00	strain
15	C_C18	2.487E-6	2.01	10.00	2.00	strain
16	C_C16	2.487E-6	2.01	10.00	2.00	strain
17	C_C14	2.487E-6	2.01	10.00	2.00	strain
18	B01_C17_P	2.487E-6	2.01	10.00	2.00	strain
19	B01_C27_P	2.487E-6	2.01	10.00	2.00	strain
20	B01_C35_P	2.487E-6	2.01	10.00	2.00	strain
21	B01_C44_P	2.487E-6	2.01	10.00	2.00	strain
22	B01_39_P	2.487E-6	2.01	10.00	2.00	strain
23	B01_55_P	2.487E-6	2.01	10.00	2.00	strain
24	B01_86_P	2.487E-6	2.01	10.00	2.00	strain
25	B01_128_P	2.487E-6	2.01	10.00	2.00	strain
26	B3_39C	2.487E-6	2.01	10.00	2.00	strain
27	M_V	1.097E-2	0.00	6.09	0.00	knots
28	M_A_T	6.225E-4	0.00	28.00	0.00	g
29	M_A_L	6.185E-4	0.00	28.00	0.00	g
30	M_A_V	1.236E-3	0.00	28.00	0.00	g
31	C_C35_9P	2.487E-7	2.01	10.00	2.00	strain
32	C_C35_10S	2.487E-7	2.01	10.00	2.00	strain
33	C_C35_10P	2.487E-7	2.01	10.00	2.00	strain
34	C_C34_11S	2.487E-7	2.01	10.00	2.00	strain
35	C_C35_11P	2.487E-7	2.01	10.00	2.00	strain
36	B1P_C44C	2.487E-7	2.01	10.00	2.00	strain
37	B01_C17_S	2.487E-7	2.01	10.00	2.00	strain
38	B01_C27_S	2.487E-7	2.01	10.00	2.00	strain
39	B01_C35_S	2.487E-7	2.01	10.00	2.00	strain
40	B01_C44_S	2.487E-7	2.01	10.00	2.00	strain
41	B01_39_S	2.487E-7	2.01	10.00	2.00	strain
42	B01_55_S	2.487E-7	2.01	10.00	2.00	strain
43	B01_86_S	2.487E-7	2.01	10.00	2.00	strain
44	B01_128_S	2.487E-7	2.01	10.00	2.00	strain
45	B3_55_P	2.487E-7	2.01	10.00	2.00	strain
46	B3_55_S	2.487E-7	2.01	10.00	2.00	strain
47	NULL	2.487E-7	0.00	0.00	0.00	NULL
48	NULL	2.487E-7	0.00	0.00	0.00	NULL

TABLE B2

POLAR SEA IMPACT TESTS FALL 1985

CONFIGURATION FILE:
FOR RAM 3 TO RAM 40

SENSOR SPECIFICATIONS

CHAN#	CHAN ID	CALIB	G. F.	EXIT.	BRIDGE	UNITS
1	C_C24	2.487E-7	2.01	10.00	2.00	strain
2	C_C26	2.487E-7	2.01	10.00	2.00	strain
3	C_C28	2.487E-7	2.01	10.00	2.00	strain
4	C_C30	2.487E-7	2.01	10.00	2.00	strain
5	C_C32	2.487E-7	2.01	10.00	2.00	strain
6	C_C34	2.487E-7	2.01	10.00	2.00	strain
7	C_C36	2.487E-7	2.01	10.00	2.00	strain
8	C_C38	2.487E-7	2.01	10.00	2.00	strain
9	S_C27	2.487E-7	2.01	10.00	2.00	strain
10	S_C35	2.487E-7	2.01	10.00	2.00	strain
11	B3_C35C	2.487E-7	2.01	10.00	2.00	strain
12	B3_C44C	2.487E-7	2.01	10.00	2.00	strain
13	B2_C17C	2.487E-7	2.01	10.00	2.00	strain
14	C_C20	2.487E-7	2.01	10.00	2.00	strain
15	C_C18	2.487E-7	2.01	10.00	2.00	strain
16	C_C16	2.487E-7	2.01	10.00	2.00	strain
17	C_C14	2.487E-7	2.01	10.00	2.00	strain
18	B01_C17_P	2.487E-7	2.01	10.00	2.00	strain
19	B01_C27_P	2.487E-7	2.01	10.00	2.00	strain
20	B01_C35_P	2.487E-7	2.01	10.00	2.00	strain
21	B01_C44_P	2.487E-7	2.01	10.00	2.00	strain
22	B01_39_P	2.487E-7	2.01	10.00	2.00	strain
23	B01_55_P	2.487E-7	2.01	10.00	2.00	strain
24	B01_86_P	2.487E-7	2.01	10.00	2.00	strain
25	B01_128_P	2.487E-7	2.01	10.00	2.00	strain
26	B3_39C	2.487E-7	2.01	10.00	2.00	strain
27	M_V	1.097E-2	0.00	6.09	0.00	knots
28	M_A_T	6.225E-4	0.00	28.00	0.00	g
29	M_A_L	6.185E-4	0.00	28.00	0.00	g
30	M_A_V	1.236E-3	0.00	28.00	0.00	g
31	C_C35_9P	2.487E-7	2.01	10.00	2.00	strain
32	C_C35_10S	2.487E-7	2.01	10.00	2.00	strain
33	C_C35_10P	2.487E-7	2.01	10.00	2.00	strain
34	C_C34_11S	2.487E-7	2.01	10.00	2.00	strain
35	C_C35_11P	2.487E-7	2.01	10.00	2.00	strain
36	B1P_C44C	2.487E-7	2.01	10.00	2.00	strain
37	B01_C17_S	2.487E-7	2.01	10.00	2.00	strain
38	B01_C27_S	2.487E-7	2.01	10.00	2.00	strain
39	B01_C35_S	2.487E-7	2.01	10.00	2.00	strain
40	B01_C44_S	2.487E-7	2.01	10.00	2.00	strain
41	B01_39_S	2.487E-7	2.01	10.00	2.00	strain
42	B01_55_S	2.487E-7	2.01	10.00	2.00	strain
43	B01_86_S	2.487E-7	2.01	10.00	2.00	strain
44	B01_128_S	2.487E-7	2.01	10.00	2.00	strain
45	B3_55_P	2.487E-7	2.01	10.00	2.00	strain
46	B3_55_S	2.487E-7	2.01	10.00	2.00	strain
47	NULL	2.487E-7	0.00	0.00	0.00	NULL
48	NULL	2.487E-7	0.00	0.00	0.00	NULL

TABLE B3

POLAR SEA IMPACT TESTS FALL 1985

CONFIGURATION FILE:
FOR RAM 1 TO RAM 40

CHAN#	CHAN ID	SENSOR LOCATIONS LONG(m.)	VERT(m.)
1	C_C24	113.4	9.1
2	C_C26	110.5	8.9
3	C_C28	109.5	8.5
4	C_C30	108.6	8.2
5	C_C32	107.7	7.9
6	C_C34	106.8	7.5
7	C_C36	106.1	7.2
8	C_C38	105.0	6.7
9	S_C27	110.0	8.2
10	S_C35	106.3	6.9
11	B3_C35C	106.3	8.9
12	B3_C44C	102.3	8.9
13	B2_C17C	114.6	11.4
14	C_C20	113.2	9.4
15	C_C18	114.1	9.8
16	C_C16	115.0	9.8
17	C_C14	115.9	10.2
18	B01_C17_P	114.6	18.1
19	B01_C27_P	110.0	17.9
20	B01_C35_P	106.3	17.8
21	B01_C44_P	102.3	17.6
22	B01_39_P	96.6	17.3
23	B01_55_P	89.8	17.1
24	B01_86_P	77.3	16.7
25	B01_128_P	60.0	16.2
26	B3_39C	96.6	8.7
27	M_V	59.0	16.0
28	M_A_T	112.5	15.1
29	M_A_L	112.5	15.1
30	M_A_V	112.5	15.1
31	C_C35_9P	106.3	7.9
32	C_C35_10S	106.3	7.5
33	C_C35_10P	106.3	7.5
34	C_C34_11S	106.3	7.1
35	C_C35_11P	106.3	7.1
36	B1P_C44C	102.3	6.4
37	B01_C17_S	114.6	18.1
38	B01_C27_S	110.0	17.9
39	B01_C35_S	106.3	17.8
40	B01_C44_S	102.3	17.6
41	B01_39_S	96.6	17.3
42	B01_55_S	89.8	17.1
43	B01_86_S	77.7	16.7
44	B01_128_S	60.0	16.2
45	B3_55_P	89.8	8.5
46	B3_55_S	89.8	8.5
47	NULL	0.0	0.0
48	NULL	0.0	0.0

TABLE B4

SENSOR CROSS REFERENCE

Channel No.	**Channel Identifier**	**Description**
1	C_C24	Compression Gauge Stem Bar Cant Frame 24
2	C_C26	Compression Gauge Stem Bar Cant Frame 26
3	C_C28	Compression Gauge Stem Bar Cant Frame 28
4	C_C30	Compression Gauge Stem Bar Cant Frame 30
5	C_C32	Compression Gauge Stem Bar Cant Frame 32
6	C_C34	Compression Gauge Stem Bar Cant Frame 34
7	C_C36	Compression Gauge Stem Bar Cant Frame 36
8	C_C38	Compression Gauge Stem Bar Cant Frame 38
9	S_C27	Bending Gauge Stem Bar Cant Frame 27
10	S_C35	Bending Gauge Stem Bar Cant Frame 35
11	B3_C35C	Bending Gauge 3rd Deck Cant Frame 35 Centre Line
12	B3_C44C	Bending Gauge 3rd Deck Cant Frame 44 Centre Line
13	B2_C17C	Bending Gauge 2nd Deck Cant Frame 17 Centre Line
14	C_C20	Compression Gauge Stem Bar Cant Frame 20
15	C_C18	Compression Gauge Stem Bar Cant Frame 18
16	C_C16	Compression Gauge Stem Bar Cant Frame 16
17	C_C14	Compression Gauge Stem Bar Cant Frame 14
18	B01_C17_P	Bending Gauge 01 Deck Cant Frame 17 Port Side
19	B01_C27_P	Bending Gauge 01 Deck Cant Frame 27 Port Side
20	B01_C35_P	Bending Gauge 01 Deck Cant Frame 35 Port Side
21	B01_C44_P	Bending Gauge 01 Deck Cant Frame 44 Port Side
22	B01_39_P	Bending Gauge 01 Deck Frame 39 Port Side
23	B01_55_P	Bending Gauge 01 Deck Frame 55 Port Side
24	B01_86_P	Bending Gauge 01 Deck Frame 86 Port Side
25	B01_128_P	Bending Gauge 01 Deck Frame 128 Port Side
26	B3_39C	Bending Gauge 3rd Deck Frame 39 Centre Line
27	M_V	Ship Speed
28	M_A_T	Transverse Acceleration
29	M_A_L	Longitudinal Acceleration
30	M_A_V	Vertical Acceleration
31	C_C35_9P	Transverse Compression Gauge Port Side (Figure 6)
32	C_C35_10S	Transverse Compression Gauge Port Side (Figure 6)
33	C_C35_10P	Transverse Compression Gauge Port Side (Figure 6)
34	C_C35_11S	Transverse Compression Gauge Port Side (Figure 6)
35	C_C35_11P	Transverse Compression Gauge Port Side (Figure 6)
36	B01_C17_S	Bending Gauge 01 Deck Cant Frame 17 Stbd. Side
37	B01_C27_S	Bending Gauge 01 Deck Cant Frame 27 Stbd. Side
38	B01_C35_S	Bending Gauge 01 Deck Cant Frame 35 Stbd. Side
39	B01_C44_S	Bending Gauge 01 Deck Cant Frame 44 Stbd. Side
40	B01_39_S	Bending Gauge 01 Deck Frame 39 Stbd. Side
41	B01_55_S	Bending Gauge 01 Deck Frame 55 Stbd. Side
42	B01_86_S	Bending Gauge 01 Deck Frame 86 Stbd. Side
43	B01_128_S	Bending Gauge 01 Deck Frame 128 Stbd. Side
45	B3_55_P	Bending Gauge 3rd Deck Frame 55 Stbd. Side
46	B3_55_S	Bending Gauge 3rd Deck Frame 55 Stbd. Side
47	NULL	No Data
48	NULL	No Data

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 1723D.
PROJECT POLAR SEA GLOBAL LOADS TESTS - OCT 1985
SUBJECT ACCELEROMETER CALIBRATIONS

SHEET 1 OF 1
DATE 85/10/02
BY DNBL/M.H.F.
CH'K. BY

	VOLTS		CHN #
TRANS + PORT	+7.76 -8.30	2g	128 (M-A-F)
SURGE + FWD	-7.37 +8.80	2g	129 (M-A-L)
HEAVE + UP	+0.23 -7.86	2g	130 (M-A-V)

GAIN = 2.0

CHN #	CHAN ID	g/VOLT	(ft/s^2)/VOLT	g/A/D
128	M-A-T	0.1245	4.01	$6.225 \times 10^{-}$
129	M-A-L	0.1237	3.98	$6.185 \times 10^{-}$
130	M-A-V	0.2472	7.96	$12.36 \times 10^{-}$

LOCATION: CF 21 - 369' 4" FWD OF AFT END
- 49' ABOVE B.L.
- ON ℄

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 1723C
PROJECT POLAR SEA GLOBAL LOADS TESTS - OCT 1983
SUBJECT DOPPLER MICROWAVE SPEED LOG CALIBRATION

SHEET ...... OF ......
DATE 25/10/83
BY MHE
CH'K. BY

CALIBRATION LEVEL 16.2 MPH = 6.09V @ A = 2.0
TUNING FORK 1.0 MPH = 0.57V ± 0.5V
3.0 MPH = 1.40V ± 0.5V
6.0 MPH = 2.49V ± 1.0V
12.0 MPH = 4.50V ± 3.0V

USE $\frac{16.2 \text{ mph}}{6.09 \text{ v}}$, TUNING FORK RESULTS TOO VARIABLE TO RELY UPON.

6080 ft. / knot
5280 ft. / mile.

6080 / 5280 = 1.1515 m.p.h / knot

1 m.p.h = 0.8684 knots

USE CALIBRATION $\left(\frac{16.2 \text{ mph}}{1.1515 \text{ mph/knot}} \middle/ 6.09\text{V}\right) \cdot \frac{.005\text{V}}{\text{A/D}}$

CALIB (27) = 0.01155 Knots / A/D COUNT

CORRECTION FOR ANGLE OF SPEED LOG = (0.95)

∴ CALIB (27) = (0.95)(0.01155) = $\boxed{0.010973 = \text{CALIB}(27)}$ ←

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 1723 D.
PROJECT Polar Sea Global Loads Tests - Oct 1985.
SUBJECT Calibration Calculation
For Strain Gauges

SHEET ...... OF ......
DATE 85/09/30
BY M.HE
CH'K. BY DNBL

$$V_{OUT} = \frac{N}{4} V_E \cdot A \cdot k \cdot \varepsilon$$

$$\frac{\varepsilon}{V_{OUT}} = \frac{4}{N \cdot V_E \cdot A \cdot k}$$

$$= \frac{4}{2 \cdot 10 \cdot 2000 \cdot (2.01)}$$

$$= \frac{1}{20100} = 4.975 \times 10^{-5} \ \varepsilon/\text{VOLT}.$$

$$= 49.75 \times 10^{-6} \ \varepsilon/\text{VOLT}.$$

$$= 49.75 \ \mu\varepsilon/\text{VOLT}$$

$$\frac{\varepsilon}{\text{A/D COUNT}} = 49.75 \ \mu\varepsilon/\text{VOLT} \times 0.005 \ \text{VOLT/A/D COUNT}$$

$$= 0.24875 \ \mu\varepsilon/\text{A/D COUNT}.$$

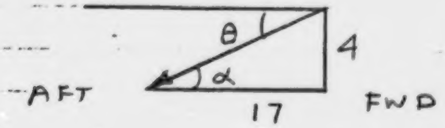
$\sim$ 50 $\mu\varepsilon$/VOLT × 10 VOLTS = 500 $\mu\varepsilon$ F.S.

Sig. Conditioner Gain = 2000. A
Gauge Factor = 2.01 K
No. of Active Arms = 2.0 N
Excitation Voltage = 10.0 volts V_E

± 10.24 VOLTS = ± 2048 A/D COUNTS.
1 A/D COUNT = 0.005 VOLTS.

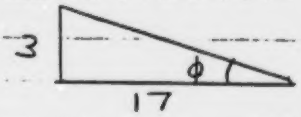
ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 1722 D (c)
PROJECT POLAR SEA IMPACT TESTS
SUBJECT ANGLE OF SPEED LOG
SHEET 1 OF 1
DATE 85/10/12
BY GNRC
CH'K. BY



$\alpha = \tan^{-1}(4/17) = 13.2° = \theta$

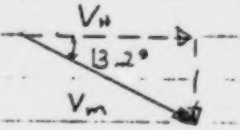
ELEVATION



$\phi = \tan^{-1}(3/17) = 10.0°$

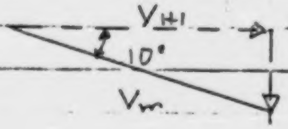
PLAN

A/ CORRECTION FOR ELEVATION :



$V_H = (\cos 13.2)(V_m) = (0.97)(V_m)$

B/ CORRECTION FOR HORIZONTAL



$V_{H1} = (\cos 10°)(V_m) = (0.98)(V_m)$

C/ TOTAL CORRECTION

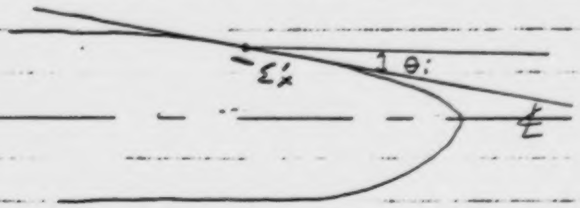
$V_{CORR.} = (V_H)(V_{H1}) = (0.97)(0.98)(V_m) = \boxed{(0.95)(V_m) = V\_}$ ✓ ←

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 1923
PROJECT POLAR SEA IMPACT TESTS
SUBJECT EFFECT OF SIDE SHELL ANGLE

SHEET 1 OF
DATE 85/11/18
BY DNBC
CH'K. BY



$$\varepsilon_x = \varepsilon_x' / [(\cos^2\theta)(1+\nu) - \nu]$$

LOCATION	ANGLE (θ_i) (DEG.)	CORRECTION FACTOR (S-e)
FR 128	< 2°	1.002
FR 86	< 2°	1.002
FR 55	6.16	1.015
FR 39	11.42	1.053
CF 44	18.3	1.146
CF 35	20.12	1.180
CF 27	22.02	1.222
CF 17	22.02	1.222

$\varepsilon_x' = \varepsilon_x \cos^2\theta + \varepsilon_y \sin^2\theta + \gamma_{xy} \sin\theta \cos\theta \doteq \varepsilon_x [(\cos^2\theta)(1+\nu) - \nu]$

ε_x = principal strain - strain parallel to ℄

ε_x' = measured strain

γ_{xy} = shearing strain $\simeq 0$

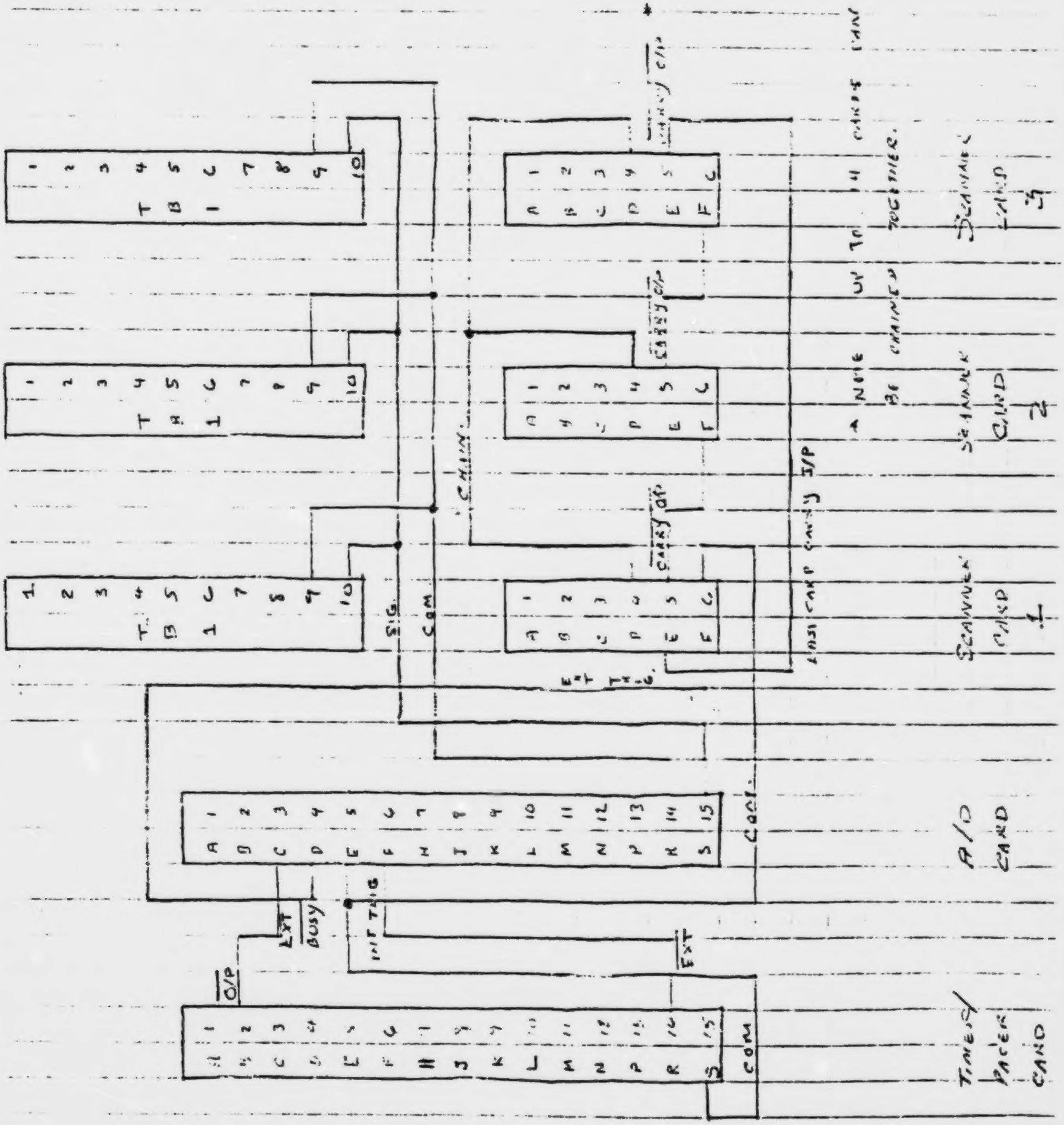
θ = angle of tangent to side shell from ℄

ν = Poisson's Ratio

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 1723C
PROJECT POLAR SEA GLOBAL LOADS
SUBJECT HP 6940B CARD EDGE CONNECTION DIAGRAM
16 SINGLE ENDED CHANNELS PER CARD.

SHEET ... OF ...
DATE 23/10/82
BY M.H.E.
CH'K. BY



CARRY O/P
TB1
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6
A B C D E F
SCANNER CARD 3
CARRY O/P
CHAIN
SCANNER CARD 2
CARRY O/P
CARRY
SIG.
COM
LAST CARD CARRY I/P
SCANNER CARD 1
EXT TRIG.
COM.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
A B C D E F H J K L M N P R S
A/D CARD
EXT BUSY
INT TRIG
EXT
O/P
COM
TIMER/PACER CARD

NOTE UP TO 14 CARDS CAN BE CHAINED TOGETHER.

APPENDIX C

CHRONOLOGICAL HISTORY OF RAMMING TESTS

On Sunday, September 29, 1985, the participants for the first (one week) leg of the global loads program arrived onboard the USCGC "Polar Sea" off Barrow, Alaska. The "Polar Sea" proceeded approximately 40 nautical miles to the North to Site 1 and Site 2 (71.41 N, 157.03 W). The following two days were spent commissioning the data acquisition system and conducting on-ice measurements. The ice was found to be composed of a mixture of one year old ice and multi-year fragments. The heaviest parts of the floes were in the range of 5 to 8 meters in thickness. A total of eight trial rams were conducted in the thinner parts of these floes, to test and verify the correct operation of the data collection system, in the evening of October 2. This was followed by two ramming tests against the heaviest ridge sections. These rams completely destroyed the principal features that had been profiled.

On October 2, a helicopter reconnaissance flight located another floe several miles away that contained thicker and more extensive multi-year ridge (Site 3 and Site 4: 71.54 N, 157.22 W). Ice profiling was conducted on October 3 and October 4. The principal multi-year ridge in this floe was found to have a keel of approximately 13 metres. In the evening of October 4 this ridge and several adjacent features, were repeatedly rammed at speeds of up to nine knots. A total of nine rams were obtained before all the thick sections of ice were substantially destroyed.

On October 5 a crew change was conducted off Barrow, Alaska, and the vessel proceeded approximately 60 nautical miles to the North, to begin the second (eight day) leg of the global loads program. A helicopter reconnaissance was deployed simultaneously and Site 5 (72.23 N, 155.04 W) was determined. The ice was composed of a mixture of first to second year with some small multi-year fragments and a ridge with a maximum thickness of approximately 13 metres. Two ramming tests were performed on October 6 at the ice edge; however, only one of these tests were recorded. A total of three rams were conducted on the ridge, on October 8, each one breaking the ridge at various locations. Three more rams were conducted at surrounding thick ice features.

On the night of October 8, Site 7 (73.00 W, 154.56 N) was found. The following two days the ridge was surveyed and found to have a maximum thickness of approximately 18 metres. The floe had open water leads throughout and was composed of first and second year ice. A total of four rams were conducted on the ridge on October 10 each one breaking the ridge at the point of impact.

Fourteen more rams, for a total of forty, were conducted on ridged ice features during the transit back to Barrow, Alaska from October 11 to October 12.

APPENDIX D

SOFTWARE DOCUMENTATION
AND
LISTING

GLOBAL LOAD ANALYSIS SOFTWARE DOCUMENTATION

General Description

The program developed for the USCGC Polar Sea Impact Tests (called "CALC1") was derived from the program written for the M.V. Kigoriak and the M.V. Robert Lemeur Impact Tests conducted in 1983. The main function of the program is to calculate and plot the global vertical load time history on the bow of the Polar Sea. The following calculations can be preformed by the program:

- longitudinal shear force and bending moment distribution
- neutral axis location
- vertical ice force on bow
- cubic spline curve fitting
- maximum and minimum values calculated
- longitudinal location of maximum and minimum bending and shear values
- location of centre of ice load on bow

Plots of all of the above as well as the strain time history, accelerations, and velocity plots can be displayed and printed. The bending and shear distributions can be displayed in animated or step-wise form. Statistical plots can also be displayed and printed.

The hardware required for the analysis program is as follows:

- HP 9816 Computer
- HP 9144A Tape Drive
- HP 9121 Disk Drive
- HP 2225A Think Jet Printer
- 2.2 MBytes of Memory

The HP Basic 3.0 operating system is required also.

A general soft key menu flow chart is illustrated in Figure D1.

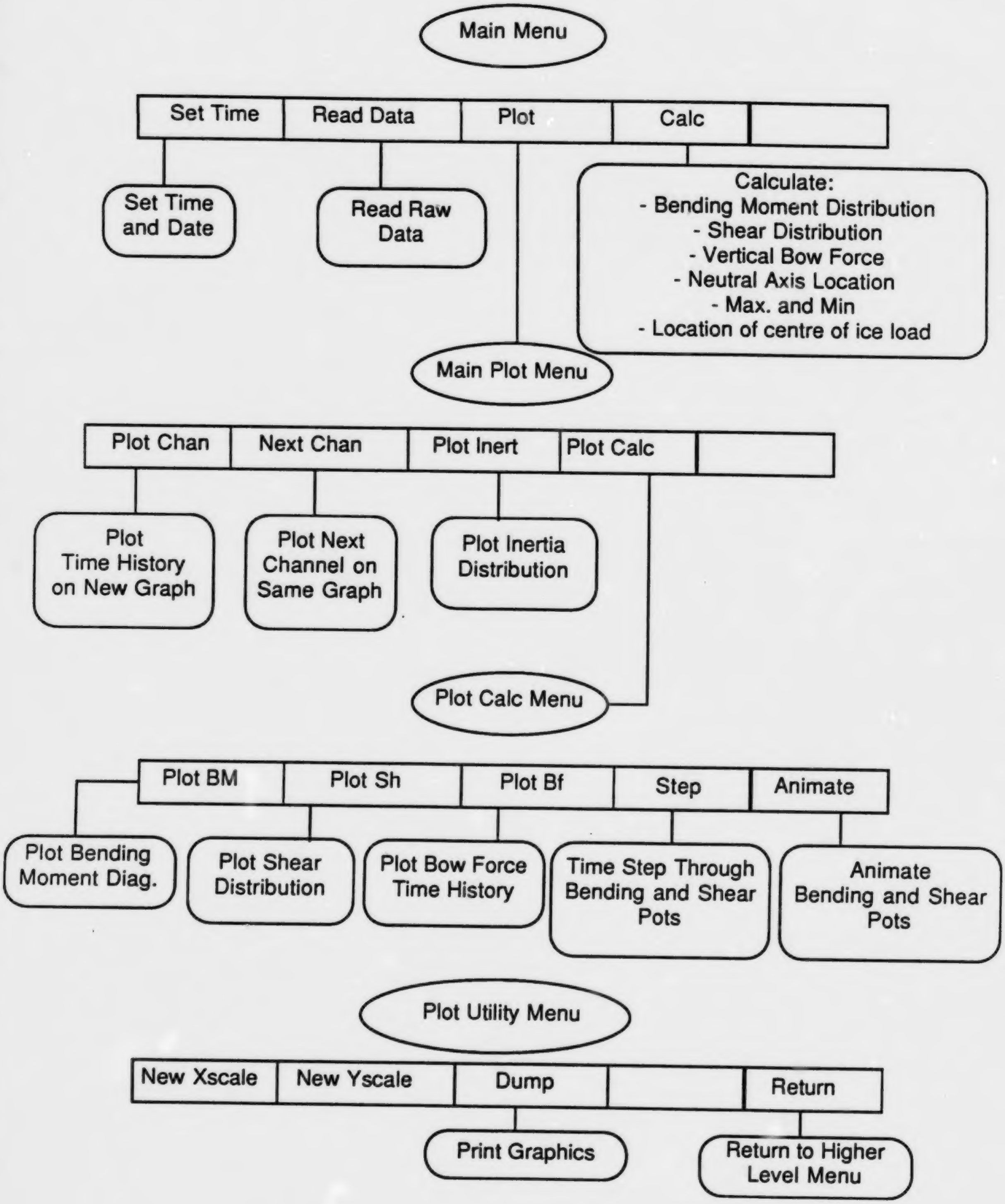

Main Menu
Set Time
Read Data
Plot
Calc
Set Time and Date
Read Raw Data
Calculate:
- Bending Moment Distribution
- Shear Distribution
- Vertical Bow Force
- Neutral Axis Location
- Max. and Min
- Location of centre of ice load
Main Plot Menu
Plot Chan
Next Chan
Plot Inert
Plot Calc
Plot Time History on New Graph
Plot Next Channel on Same Graph
Plot Inertia Distribution
Plot Calc Menu
Plot BM
Plot Sh
Plot Bf
Step
Animate
Plot Bending Moment Diag.
Plot Shear Distribution
Plot Bow Force Time History
Time Step Through Bending and Shear Pots
Animate Bending and Shear Pots
Plot Utility Menu
New Xscale
New Yscale
Dump
Return
Print Graphics
Return to Higher Level Menu

Figure D1: Global Load Analysis Menu Flow Chart
1985 USCGC POLAR SEA IMPACT TESTS

1985 Polar Sea Impact Tests
Global Load Analysis Software Operation Procedures
Arctec Canada Ltd.

1. Load the basic 3.0 system in the H.P. Series 200 computer c/w HP 9144A Tape Drive and HP9121 dual disk drive.
   Ensure there is at least 2 Mbytes of Ram in computer.
   Insert the program disk into the left hand drive. Insert the cassette data tape into the tape drive.
2. Type, Load "CALC1" then push the EXEC button.
3. Push the RUN button.
4. The Main Menu will then be displayed.
5. Push the soft key labeled SET TIME and follow instructions.
6. Push the soft key labeled CONFIG
7. Push the soft key labeled READ CONFIG
8. Type the file name ENGUNIT1 for the analysis of rams 1-2
   or type the file name ENGUNIT2 for the analysis of rams 3-40.
9. Push the soft key labelled RETURN
10. Push the soft key labelled READ DATA and follow instructions.
11. To calculate the Bow Force Time History do the following:
    - Push the soft key labelled CALCULATE
    - Enter the start time in sec.
    - Enter the end time in sec.
      (the default is all 25 seconds)
    - Push the CALC FORCE soft key
    - Push the RETURN Button
    - Push the PLOT CALC soft key
    - Push the BOW FORCE soft key
12. To plot the strain time histories push the PLOT soft key then the NEW PLOT key, then enter the channel number or ID to plot. A list of the channel numbers and the corresponding ID's are included in this appendix.
13. The scales of the plot can be changed by pushing the NEW XSCALE or NEW YSCALE soft keys.

Experiment with the program by pushing various keys. If an error occurs just push the RST button and the the RUN button. All the important variables are in common and will not be erased by this procedure. Continue to analyse data as before.

```
 ! PROGRAM "CALC1" BY D.N. BRUCE COWPER 87/01/14
OPTION BASE 1
DIM Program$[5]
Program$="CALC1"
CONTROL KBD,15;1
 !
 ! PROGRAM FOR RAMS 1-40
 !
 !  PROGRAM DESCRIPTION:
 !
 ! THIS PROGRAM IS TO BE USED FOR THE FALL 1985 POLAR SEA IMPACT TESTS
 ! THE PROGRAM HAS THE FOLLOWING CAPABILITIES:
 !
 !      1. READ THE DATA FROM RAMMING TESTS
 !      2. CALCULATE THE FOLLOWING FOR EACH TIME STEP:
 !         A.THE BENDING MOMENT AT 8 FRAMES
 !         B.THE SHEAR AT 9 FRAMES
 !         C.THE LOCATION OF THE LOAD
 !         D.THE VERTICAL BOW FORCE
 !         E.THE LOCATION OF THE NEUTRAL AXIS
 !      3. PLOT ALL OF THE ABOVE
 !
 ! HARDWARE CONFIGURATION
 !
 !      -1 OF HP SERIES 200 MODEL 16 DESKTOP COMPUTER (HP9816)
 !      -2 1-MEGABYTE MEMORY BOARD
 !
 ! SOFTWARE : COMPLETE HP BASIC 3.0
 !
 ! DATA REPRESENTATION
 !
 !  Engineering units=(Data(Rd,Chn)-Base_L(Chn))*Calib(chn)
 !
 ! COORDINATE SYSTEM
 !
 ! ORIGIN  0,0,0 ----- AFT END, CENTRE LINE, BASE LINE
 !
 ! + TO STB
 ! + TO BOW
 ! + VERTICAL
 !
 !================
 ! REAL ARRAYS
 !===============
 !
 COM REAL Calib(50)    ! CALIBRATION FOR EACH SENSOR (ENG. UNITS/A/D COUNT)
 COM REAL Long(50)     ! LONGITUDINAL LOCATION OF SENSOR (m)
 COM REAL Vert(50)     ! VERTICAL LOCATION OF GAUGES (m FROM BASE LINE)
 DIM Trans(50)         ! TRANSVERSE LOCATION OF GAUGES ( NOT USED)
 DIM Fr(50)            ! FRAME LOCATION OF GAUGES (NOT USED)
 DIM Offs(50)          ! OFFSET OF GAUGES (NOT USED)
 COM REAL Gf(50)       ! GAUGE FACTOR
 COM Brge(50)          ! BRIDGE CONFIG
 COM REAL Excit(50)    ! EXCITATION (VOLTS)
 COM REAL D(10)        ! INVERSE OF VERTICAL DIST. BETWEEN GAUGES OR DIST.
                       ! OR INERSE OF DIST. TO NEUTRAL AXIS (m^-1)
 COM REAL Inertia(10)  ! INST. FRAME AREA MOMENT OF INERTIA (m^4)
 COM REAL Base_1(48)   ! BASE LINE AVERAGES (A/D COUNTS)
```

```
59   COM REAL Loc_load(2500)! LOCATION OF THE LOAD (m FROM AFT END)
60   COM REAL Loc_frame(10)! INST. FRAME LOC. & BOW & STERN (m FROM AFT END)
61   COM REAL Sh_frame(11) ! LOCATION OF CALCULATED SHEAR  (m FROM AFT END)
62   COM REAL Bm(2500,11)  ! BENDING MOMENT(Nm)
63   COM REAL Sh(2500,11)  ! SHEAR(N)
64   COM REAL Bf(2500)     ! BOWF(N)
65   COM REAL Neut(2500,6)  ! NEUTRAL AXIS LOCATION (m from base line)
66   COM REAL S_e(10)      ! TRANSFORMATION CONSTANT FOR STRAIN TO CENTRE LINE
67   COM REAL Bm5(40)      ! PEAK BENDING STRESS FOR EACH RAM
68   COM REAL Sp(40)       ! IMPACT VELOCITY FOR EACH RAM
69   COM REAL Bfm(40)      ! PEAK VERTIACL BOW FORCE FOR EACH RAM
70   !
71   !====================
72   !INTEGER ARRAYS
73   !====================
74   !
75   COM INTEGER Data(2500,48) BUFFER   ! DATA FROM DATA DISC
76   !
77   !============================
78   ! STRING ARRAYS
79   !===============================
80   !
81   COM Id$(50)[10]        ! CHANNEL ID
82   COM Title$[80]         ! PLOT TITLE
83   COM Ram$[10]           ! RAM LABEL (eg. RAM12)
84   DIM X_title$[50]       ! X AXIS TITLE FOR PLOT
85   DIM Y_title$[50]       ! Y AXIS TITLE FOR PLOT
86   DIM X_unit$[6]         ! X AXIS UNITS
87   DIM Y_unit$[6]         ! Y AXIS UNITS
88   COM Unit$(50)[6]       ! UNITS FOR EACH SENSOR
89   DIM D1$[12]            ! RIGHT HAND DISC DRIVE
90   DIM D0$[12]            ! LEFT HAND DISC DRIVE
91   DIM Chan_id$[10]       ! INPUT FOR CHANNEL ID TO PLOT
92   DIM Unit_scale$(11)[1]! SCALE FOR PLOTTING
93   DIM File$[34]          ! NAME OF FILE TO STORE AND MSU
94   DIM Config$[8]         ! NAME OF CONFIGURATION FILE
95   COM Ac_time$[8]        ! ACQUSITION TIME
96   COM Ac_date$[11]       ! ACQUISTION DATE
97   COM Fr$(10)[5]          ! FRAME LABELS
98   !
99   !=====================
100  ! INTEGERS
101  !=======================
102  !
103  INTEGER I,J,K,L        ! LOOP COUNTERS
104  INTEGER Rdg            ! READING NUMBER
105  COM INTEGER Rdg1,Rdg2  ! FIRST READING/LAST READING
106  INTEGER Position       ! POSITION OF CURSOR
107  COM INTEGER Scan_rate  ! SCAN RATE
108  COM INTEGER Nchns      ! NUMBER OF CHANNELS
109  COM INTEGER Nrdgs      ! NUMBER OF READINGS
110  COM INTEGER Chn        ! CHANNEL NUMBER TO PLOT
111  !
112  !========================
113  !   REAL VARIBLES
114  !========================
115  !
116  COM REAL Xmin,Xmax     ! USED FOR PLOTTING
117  COM REAL Nbytes        ! NUMBER OF BYTES IN Data FILE
118  REAL Ir,Linc,Xscale,Yscale ! USE  FOR PLOTTING
```

```
119   COM REAL T1_calc,T2_calc   ! FIRST AND LAST TIME FOR CALCULATION ROUTINE
120   COM T_bf,T_sh,T_bm     ! TIMES AT CALCULATED MAXIMUMS AND MINIMUMS
121   COM Sh_min,Sh_max      ! MIN AND MAX SHEAR
122   COM Bf_max             ! MAX BOW FORCE
123   COM Bm_min             ! MAXIMUM NEGATIVE BENDING MOMENT
124   COM Sh1,Sh2            ! MAX AND MIN SHEAR AT TIME OF MAX FORCE
125   COM L_sh,L_sh1,L_sh2,L_bm ! LOCATION OF MAXIMUMS AND MINIMUMS
126   COM Speed              ! IMPACT SPEED OF VESSEL
127   !
128   !======================================
129   ! CUBIC SPLINE VARIABLES
130   !=======================================
131   REAL Xp(150),Yp(150)
132   REAL Xsh(150),Ysh(150)
133   REAL Aa(12,12)
134   REAL Kk(12,1)
135   REAL Dd(12,1)
136   REAL Xx(12),Yy(12)
137   REAL Deltax(12)
138   REAL Deltay(12)
139   REAL Ddd(12)
140   !
141   !
142   !==========================
143   !   CONSTANT DECLARATIONS
144   !==========================
145   !
146   Ref_flg=1                 ! FOR REFERENCE LINE
147   I$=CHR$(129)              ! INVERSE VIDEO
148   N$=CHR$(128)              ! NORMAL DISPLAY
149   D1$=":,700,0"             ! DISC DRIVE TO READ DATA ON
150   D0$=":,700,0"             ! DISC DRIVE TO STORE DATA ON
151   PLOTTER IS CRT,"INTERNAL" ! DEFAULT PLOTTER
152   PRINTER IS 1
153   Pen_flg=-1                ! FOR PEN PLOTTER
154   Grid_flg=1                ! GRIDS ON PLOTS
155   !==========================
156   ! CONFIGURATION PARAMETERS
157   !==========================
158   !
159   Table_flg=1           ! FIRST TABLE
160   Chn_p=12              ! CHANNELS DISPLAYED PER PAGE-1
161   Row_o=4               ! FIRST ROW FOR CHANNEL DISCRIPTION
162   !
163 Title_1:IMAGE 5A,2X,10A,2X,7A,7X,7A,2X,7A,2X,7A,2X,7A
164 Title_2:IMAGE 5A,2X,10A,5X,10A,5X,10A,2X,7A,2X,7A,2X,7A
165 Values1:IMAGE DDD,4X,10A,2X,MD.DDDESZ,5X,D.DD,4X,MDD.DD,4X,D.DD,5X,7A
166 Values2:IMAGE DDD,4X,10A,5X,MDDD.D,9X,MDDD.D,3X,MDDD.D,5X,MDDD
167   !
168   !=============================================
169   ! PLOTTING PARAMETERS
170   !===============================================
171 Max_table:IMAGE 5X,16A,MDDD.DD,15A,DD.DD,5A,7A,12A
172   DATA "T","G","M","k","","m","u","n","p","f","a"
173   READ Unit_scale$(*)
174   !
175   ! DEFAULT SCALES
176   !
177   Def_xmin=0
178   Def_xmax=25
```

```
179   !
180   !=============================================
181   !   SHIP PROPERTIES
182   !==============================================
183   !
184   !    1,  2,  3, 4,  5,   6,   7,   8,   9 ,  10
185   !
186   !FR 276,129,85 ,55 ,39 ,CF44,CF35,CF27,CF17,BOW   ! ORDER OF FRAMES
187   DATA FR276,FR128,FR85,FR55,FR39,CF44,CF35,CF27,CF17,BOW
188   READ Fr$(*)
189   !
190   ! TRANSFORMATION OF STRAIN TO BE PARALLEL TO CENTRE LINE
191   DATA 0,1.002,1.002,1.015,1.053,1.146,1.180,1.222,1.222,0
192   READ S_e(*)
193   ! MOMENTS OF INERTIA
194   DATA 0,100,100,130,68.5,27.7,18.6,10.4,7.0,0  ! m^4 ADJUSTED EST.85/12/03
195   READ Inertia(*)         ! AREA MOMENT OF INERTIA AT EACH FRAME LOC.
196   !
197   E=2.07E+11              ! ELASTIC MODULUS FOR THE STEEL  ( Pa)
198   Nfrms=8                 ! NUMBER OF FRAMES INSTRUMENTED FOR BENDING
199   L_vsl=121.70            ! LENGTH OF VESSEL IN (m)
200   !
201   ! DISTANCE IN METERS TO FRAMES FROM AFT END
202   DATA 0,60.05,77.72,89.92,95.5,102.63,106.60,110.05,114.53,121.7,121.7
203   READ Loc_frame(*)       ! LOCATION OF INSTRUMENTED FRAMES
204   !
205   Sh_frame(1)=0
206   FOR I=2 TO 10
207     Sh_frame(I)=Loc_frame(I-1)+.5*(Loc_frame(I)-Loc_frame(I-1))
208   NEXT I
209   Sh_frame(11)=Loc_frame(10)
210   ! ASSIGNMENTS
211   !
212   ASSIGN @Buffer TO BUFFER Data(*);WORD
213   !
214   PRINT CHR$(12)
215   !====================================================
216 Main:  !   MAIN PROGRAM
217   !====================================================
218   PRINTER IS 1
219   ON KEY 5 LABEL "CONFIGURE",1 GOTO Configure
220   ON KEY 6 LABEL "READ DATA",1 GOSUB Read_data
221   ON KEY 7 LABEL "CALCULATE",1 GOTO Calculate
222   ON KEY 8 LABEL "PLOT DATA",1 GOTO Plot_data
223   ON KEY 9 LABEL "STORE CALC",1 GOSUB Store_calc
224   ON KEY 4 LABEL "READ CALC",1 GOSUB Read_calc
225   ON KEY 3 LABEL "STORE DATA",1 GOSUB Store_data
226   ON KEY 2 LABEL "LABEL FIGURE",1 GOSUB Label_figure
227   ON KEY 1 LABEL "PRINT SPEC",1 GOTO Dump_spec
228   ON KEY 0 LABEL "SET TIME",1 GOSUB Set_time
229 Wait_main: !
230   PRINT TABXY(24,7),"POLAR SEA IMPACT TESTS FALL 1985"
231   PRINT TABXY(32,8),"ARCTEC CANADA LTD."
232   PRINT TABXY(34,9),"PROGRAM "&Program$
233   PRINT TABXY(34,10),"FOR RAMS 1-40"
234   PRINT TABXY(34,12),DATE$(TIMEDATE)
235   PRINT TABXY(34,13),TIME$(TIMEDATE)
236   GOTO Wait_main
237   !
238   !=============================================
239 Store_calc:  !
240   !==========================================
241   DISP "INSERT THE CALCULATION DISC INTO THE RIGHT HAND DRIVE THEN PUSH CONT
"
242   Calc_prog$=Program$
243   Records=INT((16*8+10)/256)+1
244   CREATE BDAT Ram$&D0$,Records
245   ASSIGN @Path TO Ram$&D0$
246   OUTPUT @Path;TIMEDATE,Calc_prog$,Bf_max,Sh1,Sh2,Bm_min,9m5_min,T_bf,T_bm,T
bm5,L_sh1,L_sh2,L_bm,T1_calc,T2_calc,Scan_rate,Speed
247   ASSIGN @Path TO *
248   BEEP
249   DISP ""
250   RETURN
251   !==============================================
252 Read_calc:  !
253   !==============================================
254   IF S_flg=0 THEN
255     INPUT "ENTER THE RAM NUMBER TO READ",Ram_no$
256   END IF
257   Ram$="RAM"&Ram_no$
258   DISP "READING CALCULATED QUANTITIES FOR ";Ram$
259   ASSIGN @Path TO Ram$&D0$
260   ENTER @Path;Calc_time,Calc_prog$,Bf_max,Sh1,Sh2,Bm_min,Bm5_min,T_bf,T_bm,T
bm5,L_sh1,L_sh2,L_bm,T1_calc,T2_calc,Scan_rate,Speed
261   ASSIGN @Path TO *
262   IF S_flg=0 THEN
263     PRINT "TIME/DATA  OF ANALYSIS ";TIME$(Calc_time);"/";DATE$(Calc_time)
264     PRINT "PROGRAM USED ";Calc_prog$
265     PRINT Ram$
266     DISP ""
267     PRINT CHR$(12)
268   END IF
269   RETURN
270   !=========================================
271 Set_time:  !
272   INPUT "ENTER THE DATE DD/MMM/YYYY",Date$
273   INPUT "ENTER THE TIME HH:MM:SS",Time$
274   SET TIMEDATE DATE(Date$)+TIME(Time$)
275   RETURN
276   !=========================================
277 Read_data:                          !
278   !=========================================
279   Q$=""
280   INPUT "DO YOU WANT TO READ THE DATA FROM THE HARD DISC (Y,N)",Q$
281   IF Q$<>"Y" THEN
282     INPUT "INSERT THE DATA DISC INTO THE RIGHT HAND DRIVE,PUSH CONT",Cont$
283     ASSIGN @Path1 TO "TITLE"&D1$
284     ASSIGN @Path2 TO "DATA"&D1$
285   ELSE
286 Read_hdata:  !
287     D1$=":,707,0"
288     IF Auto_flg=0 THEN INPUT "ENTER THE RAM #",Ram_no
289     Ram$="RAM"&VAL$(Ram_no)
290     ASSIGN @Path1 TO Ram$&"_L"&D1$
291     ASSIGN @Path2 TO Ram$&D1$
292   END IF
293   PRINT CHR$(12)
294   MAT Data= (0)
295   ASSIGN @Buffer TO BUFFER Data(*);WORD
```

```
296   RESET @Buffer
297   ENTER @Path1;Ram$,Nchns,Nrdgs,Scan_rate,Start_time
298   PRINT TABXY(20,6),"EVENT: ";Ram$
299   PRINT TABXY(20,7),"NUMBER OF CHANNELS: ";Nchns
300   PRINT TABXY(20,8),"READINGS PER CHANNEL: ";Nrdgs
301   PRINT TABXY(20,9),"SCAN RATE (READINGS/CHANNEL/SEC): ";Scan_rate
302   PRINT TABXY(20,10),"TEST DATE: ";DATE$(Start_time)
303   PRINT TABXY(20,11),"START TIME: ";TIME$(Start_time)
304   Ac_date$=DATE$(Start_time)
305   Ac_time$=TIME$(Start_time)
306   DISP "READING CHANNEL WAVEFORM DATA"
307   T1=TIMEDATE
308   TRANSFER @Path2 TO @Buffer;WAIT
309   ASSIGN @Path1 TO *
310   ASSIGN @Path2 TO *
311   T2=TIMEDATE
312   PRINT CHR$(12)
313   DISP "TIME TO READ DATA ON DISC = ";T2-T1
314   DISP "CALCULATING BASE LINE"
315   GOSUB Base_calc
316   DISP ""
317   BEEP
318   RETURN
319   !
320   !==========================================
321 Store_data:                          !
322   !================================================
323   Q$=""
324   INPUT "DO YOU WANT TO STORE ON THE DATA FROM THE HARD DISC (Y,N)",Q$
325   IF Q$<>"Y" THEN
326     D1$=":,702,0"
327     INPUT "INSERT THE DATA DISC INTO THE RIGHT HAND DRIVE,PUSH CONT",Cont$
328     ASSIGN @Path1 TO "TITLE"&D1$
329     ASSIGN @Path2 TO "DATA"&D1$
330   ELSE
331     D1$=":,707,0"
332     DISP "CREATING FILES"
333     CREATE BDAT Ram$&D1$,1000,250
334     CREATE ASCII Ram$&"_L"&D1$,1
335     ASSIGN @Path1 TO Ram$&"_L"&D1$
336     ASSIGN @Path2 TO Ram$&D1$
337   END IF
338   DISP "STORING DATA"
339   PRINT CHR$(12)
340   ASSIGN @Buffer TO BUFFER Data(*);WORD
341   Start_time=TIME(Ac_time$)+DATE(Ac_date$)
342   OUTPUT @Path1;Ram$,Nchns,Nrdgs,Scan_rate,Start_time
343   T1=TIMEDATE
344   Nbytes=Nrdgs*2.*Nchns
345   CONTROL @Buffer,4;Nbytes
346   TRANSFER @Buffer TO @Path2;WAIT
347   ASSIGN @Path1 TO *
348   ASSIGN @Path2 TO *
349   T2=TIMEDATE
350   PRINT CHR$(12)
351   DISP "TIME TO STORE DATA ON DISC = ";T2-T1
352   DISP ""
353   BEEP
354   RETURN
355   !
```

```
356   !====================================================
357 Calculate:  !
358   GOSUB Init_calc
359   ON KEY 5 LABEL "CALC FORCE",1 GOSUB Calc_force
360   ON KEY 6 LABEL "CALC MAX.",1 GOSUB Calc_max
361   ON KEY 7 LABEL "CALC LOCATION",1 GOSUB Calc_loc
362   ON KEY 8 LABEL "",1 GOTO Wait_calc
363   ON KEY 9 LABEL "RETURN",1 GOTO End_calc
364   ON KEY 0 LABEL "CALC N.A.",1 GOSUB Calc_na
365   ON KEY 1 LABEL "AUTO",1 GOSUB Auto_calc
366   ON KEY 2 LABEL "ORDER LOC",1 GOSUB Order_loc
367   ON KEY 3 LABEL "SUMM",1 GOSUB Summ_calc
368 Wait_calc:GOTO Wait_calc
369 End_calc:           !
370   PRINT CHR$(12)
371   GOTO Main
372   !
373   !============================
374 Summ_calc:  !
375   !======================
376   S_flg=1
377   R_s$=""
378   INPUT "DO YOU WANT TO READ ALL CALCS",R_s$
379   Q$=""
380   INPUT "DO YOU WANT A HARD COPY (Y/N)",Q$
381   IF Q$="Y" THEN
382     PRINTER IS 701
383   ELSE
384     PRINT CHR$(12)
385     PRINTER IS 1
386   END IF
387   PRINT ""
388   PRINT ""
389   PRINT USING "36X,7A";"TABLE 5"
390   PRINT USING "25X,31A";"SUMMARY OF IMPACT DATA ANALYSIS"
391   PRINT ""
392   PRINT USING "3A,9X,6A,13X,9A,13X,21A ";"RAM","IMPACT","BOW FORCE","MEASURE
D BEND. STRESS"
393   PRINT USING "3A,9X,4A,12X,4A,7X,4A,12X,4A,5X,4A,5X,4A ";"No.","VEL.","MAX.
","TIME","MAX.","TIME","LOC."
394   PRINT USING "12X,7A,9X,4A,7X,6A,10X,5A,4X,6A ";"(knots)","(MN)","(Sec.)","
(MPa)","(Sec.)"
395   PRINT ""
396   FOR I=1 TO 40
397     IF I<>12 THEN
398       IF I<>16 THEN
399         Ram_no$=VAL$(I)
400  IF R_s$="Y" THEN GOSUB Read_calc
401   R_$=Ram$[4,5]
402   IF I=18 THEN Speed=6.0
403   IF I=22 THEN Speed=6.0
404   IF I=24 THEN Speed=7.0
405   IF I=27 THEN Speed=6.0
406   IF I=36 THEN Speed=9.0
407   IF I=18 OR I=22 OR I=24 OR I=27 OR I=36 THEN R_$=Ram$[4,5]&"(1)"
408   IF I=28 OR I=29 OR I=30 THEN R_$=Ram$[4,5]&"(2)"
409   PRINT USING "6A,7X,DD.D,12X,DD.D,7X,DD.D,11X,MDD.D,5X,DD.D,4X,4A ";R_$,Spe
ed,Bf_max,T_bf,BmS_min*1.E-6,TbmS,Fr$(S)
410         Sp(I)=Speed
411         BmS(I)=BmS_min
```

```
412         Bfm(I)=Bf_max
413       END IF
414     END IF
415   NEXT I
416   PRINT ""
417   PRINT ""
418   PRINT "(1)  DATA FROM BRIDGE VELOCITY INDICATOR"
419   PRINT "(2)  SPEED DATA NOT AVAILABLE"
420   S_flg=0
421   RETURN
422   !
423 P_sum_calc:  !
424   Grid_flg=-1
425   ON KEY 5 LABEL "FORCE VEL.",1 GOSUB P_f_v
426   ON KEY 6 LABEL "BEND  FORCE",1 GOSUB P_b_f
427   ON KEY 7 LABEL "HIST  BEND",1 GOSUB P_h_b
428   ON KEY 8 LABEL "HIST  FORCE",1 GOSUB P_h_f
429   ON KEY 9 LABEL "RETURN",1 GOTO Plot_calc
430   ON KEY 0 LABEL "DUMP GRAPHICS",1 GOSUB Dump_graphics
431   ON KEY 1 LABEL "PEN PLOTTER",1 GOSUB Pen_plot
432   ON KEY 2 LABEL "GRAPHICS OFF",1 GOSUB Off_graphics
433   ON KEY 3 LABEL "",1 GOTO Wait_p_summ
434   ON KEY 4 LABEL "",1 GOTO Wait_p_summ
435 Wait_p_summ:GOTO Wait_p_summ
436   !
437 Off_graphics:GRAPHICS OFF
438   RETURN
439                          !
440                          !
441  !=============
442 P_h_f:                      !
443  !=============
444   !
445   Title$="HISTOGRAM OF PEAK VERTICAL BOW FORCE"
446   Y_title$="NUMBER OF RAMS"
447   X_title$="PEAK VERTICAL BOW FORCE  (MN)"
448   X_unit$=""
449   Y_unit$=""
450   Ymin=0
451   Ymax=15
452   Xmin=0
453   Xmax=30
454   GOSUB Find_scale
455   GOSUB Plot_frame
456   CLIP OFF
457   LORG 5
458   PEN 3
459   FOR K=1 TO 10
460     Hght=0
461     FOR I=1 TO 40
462       IF Bfm(I)<K*Xmax/10 AND Bfm(I)>(K-1)*Xmax/10 THEN
463         Hght=Hght+1
464       END IF
465     NEXT I
466     MOVE Xmax/10*(K-1),0
467     RECTANGLE Xmax/10,Hght,EDGE
468   NEXT K
469   RETURN
470                               !
471  !===========
472 P_h_b:                         !
473  !=============
474   !
475   Title$="HISTOGRAM OF MAXIMUM BENDING STRESS"
476   Y_title$="NUMBER OF RAMS"
477   X_title$="MAXIMUM BENDING STRESS (MPa.)"
478   X_unit$=""
479   Y_unit$=""
480   Ymin=0
481   Ymax=20
482   Xmin=-50
483   Xmax=0
484   GOSUB Find_scale
485   GOSUB Plot_frame
486   CLIP OFF
487   LORG 5
488   PEN 1
489   FOR K=1 TO 10
490     Hght=0
491     FOR I=1 TO 40
492       IF BmS(I)*1.E-6>K*Xmin/10 AND BmS(I)*1.E-6<(K-1)*Xmin/10 THEN
493         Hght=Hght+1
494       END IF
495     NEXT I
496     MOVE Xmin/10*(K-1),0
497     RECTANGLE Xmin/10,Hght,FILL,EDGE
498   NEXT K
499   RETURN
500                                    !
501   !=====================================
502 P_f_v:  !
503   !=====================================
504   !
505   Title$="PEAK FORCE VELOCITY RELATIONSHIP"
506   Y_title$="PEAK VERTICAL IMPACT FORCE (MN)"
507   X_title$="RAMMING VELOCITY (m/s)"
508   X_unit$=""
509   Y_unit$=""
510   Ymin=0
511   Ymax=50
512   Xmin=0
513   Xmax=8
514   GOSUB Find_scale
515   GOSUB Plot_frame
516   CLIP OFF
517   LORG 5
518   FOR I=1 TO 40
519     IF Sp(I)>0 THEN
520       MOVE Sp(I)*.5144,Bfm(I)
521       LABEL "+"
522     END IF
523   NEXT I
524   !
525   ! COMPARISONS
526   !
527   Displ=9.79    ! Kg*1E6  DISPLACEMENT OF VESSEL
528   Bow_ang=25    ! DEGREES APPROXIMATE STEM ANGLE AT ICE LINE
529   !
530   LORG 2
531   !
```

```
532   ! JOHANSSON ET. AL.
533   !
534   MOVE 0,0
535   LINE TYPE 1
536   FOR I=1 TO 110
537     PLOT I/20,I/20*Displ^.9*COS(Bow_ang),-1
538   NEXT I
539   MOVE Xmax*.01,Ymax*.95
540   PLOT Xmax*.1,Ymax*.95,-1
541   LABEL " JOHANSSON ET. AL."
542   !
543   ! ENVELOPE TO KIGORIAK DATA
544   !
545   LINE TYPE 5
546   MOVE 0,0
547   FOR I=1 TO 55
548     PLOT I/10,2.34*SQR(I/10)*Displ^.9*COS(Bow_ang),-1
549   NEXT I
550   MOVE Xmax*.01,Ymax*.9
551   PLOT Xmax*.1,Ymax*.9,-1
552   LINE TYPE 1
553   LABEL " 1983 KIGORIAK TESTS"
554   !
555   !
556   MOVE Xmax*.05,Ymax*.85
557   LABEL "+"
558   MOVE Xmax*.1,Ymax*.85
559   LABEL " 1985 POLAR SEA TESTS"
560   !
561   RETURN
562   !
563   RETURN
564   !==============================
565 P_b_f:  !
566   !======================================
567   !
568   Title$="VERTICAL FORCE vs. DECK STRAIN"
569   X_title$="PEAK BENDING STRAIN AT FRAME 39 (ue)"
570   Y_title$="VERTICAL BOW FORCE (MN)"
571   X_unit$=""
572   Y_unit$=""
573   Ymin=0
574   Ymax=40
575   Xmin=0
576   Xmax=300
577   GOSUB Find_scale
578   GOSUB Plot_frame
579   CLIP OFF
580   LORG 5
581   FOR I=1 TO 40
582     MOVE -Bm5(I)/E*1.E+6,Bfm(I)
583     LABEL "+"
584   NEXT I
585   RETURN
586   !
587   !=================
588 Auto_calc:  !
589   !================
590   Auto_flg=1
591   INPUT "ENTER THE FIRST RAM TO ANALYSE",Auto_n1
```

```
592    INPUT "ENTER THE LAST RAM TO ANALYSE",Auto_n2
593    FOR Auto_ram=Auto_n1 TO Auto_n2
594      Ram_no=Auto_ram
595      GOSUB Read_hdata
596      GOSUB Init_calc
597      GOSUB Calc_force
598      GOSUB Calc_max
599      GOSUB P_bf
600      Bf_flg=1
601      DUMP GRAPHICS
602      PRINTER IS 701
603      GOSUB Dump_spec
604      PRINTER IS 1
605      GOSUB Store_calc
606    NEXT Auto_ram
607    Auto_flg=0
608    RETURN
609    !==========================================
610 Calc_na:  !
611    !==========================================
612    DISP "CALCULATING NEUTRAL AXIS"
613    J=0
614    FOR Rdg=Rdg1 TO Rdg2
615    ! FR 55
616      IF Ram$="RAM39" THEN
617        S01=((Data(Rdg,42)-Base_l(42))*Calib(42))*S_e(4)
618      ELSE
619        S01=.5*((Data(Rdg,42)-Base_l(42))*Calib(42)+(Data(Rdg,23)-Base_l(23))*
Calib(23))*S_e(4)
620      END IF
621      S03=.5*((Data(Rdg,45)-Base_l(45))*Calib(45)+(Data(Rdg,46)-Base_l(46))*Ca
lib(46))*S_e(4)
622      IF S01-S03<>0 THEN Neut(Rdg,1)=Vert(42)-S01/(S01-S03)/D(4)
623      ! FR 39
624      IF Ram$="RAM14" THEN
625        S01=((Data(Rdg,22)-Base_l(22))*Calib(22))*S_e(5)
626      ELSE
627        S01=.5*((Data(Rdg,22)-Base_l(22))*Calib(22)+(Data(Rdg,41)-Base_l(41))*
Calib(41))*S_e(5)
628      END IF
629      S03=(Data(Rdg,26)-Base_l(26))*Calib(26)
630      IF S01-S03<>0 THEN Neut(Rdg,2)=Vert(41)-S01/(S01-S03)/D(5)
631      ! CF 44
632      S01=.5*((Data(Rdg,21)-Base_l(21))*Calib(21)+(Data(Rdg,40)-Base_l(40))*Ca
lib(40))*S_e(6)
633      S03=(Data(Rdg,12)-Base_l(12))*Calib(12)
634      IF (S01-S03)<>0 THEN Neut(Rdg,3)=Vert(40)-S01/(S01-S03)/D(6)
635      ! CF 35
636      S01=.5*((Data(Rdg,20)-Base_l(20))*Calib(20)+(Data(Rdg,39)-Base_l(39))*Ca
lib(39))*S_e(7)
637      S03=(Data(Rdg,11)-Base_l(11))*Calib(11)
638      IF S01-S03<>0 THEN Neut(Rdg,4)=Vert(39)-S01/(S01-S03)/D(7)
639      ! CF27
640      IF Ram$="RAM14" THEN
641        S01=((Data(Rdg,19)-Base_l(19))*Calib(19))*S_e(8)
642      ELSE
643        S01=.5*((Data(Rdg,19)-Base_l(19))*Calib(19)+(Data(Rdg,38)-Base_l(38))*
Calib(38))*S_e(8)
644      END IF
645      Stm=(Data(Rdg,9)-Base_l(9))*Calib(9)
```

```
646      IF S01-Stm<>0 THEN Neut(Rdg,5)=Vert(19)-S01/(S01-Stm)/D(8)
647      ! CF 17
648      IF Ram$="RAM39" OR Ram$="RAM14" THEN
649        S01=((Data(Rdg,18)-Base_1(18))*Calib(18))*S_e(9)
650      ELSE
651        S01=.5*((Data(Rdg,18)-Base_1(18))*Calib(18)+(Data(Rdg,37)-Base_1(37))*
Calib(37))*S_e(9)
652      END IF
653      S03=(Data(Rdg,13)-Base_1(13))*Calib(13)
654      IF S01-S03<>0 THEN Neut(Rdg,6)=Vert(37)-S01/(S01-S03)/D(9)
655    NEXT Rdg
656    DISP ""
657    BEEP
658    RETURN
659    !==========================================================
660 Init_calc: !
661    !=========================================================
662    IF Vert(44)=0 THEN
663      BEEP
664      DISP "YOU MUST READ THE CONFIGURATION FILE FIRST"
665      WAIT 2
666      DISP ""
667      GOTO Main
668    END IF
669    !
670    ! INVERSE OF DISTANCES BETWEEN GAUGES OR DISTANCE FROM GAUGE
671    ! TO NEUTRAL AXIS
672    !
673    D(1)=0
674    D(2)=1/(Vert(44)-7.41)
675    D(3)=1/(Vert(43)-7.86)
676    D(4)=1/(Vert(42)-Vert(45))
677    D(5)=1/(Vert(41)-8.4)  !Vert(26))
678    D(6)=1/(Vert(40)-10.5)  !Vert(12))
679    D(7)=1/(Vert(39)-11.3)   !Vert(11))
680    D(8)=1/(Vert(38)-12.3)
681    D(9)=1/(Vert(37)-12.9)     !Vert(13))
682    D(10)=0
683    !
684    T1_calc=0
685    T2_calc=25
686    IF Auto_flg=0 THEN
687      INPUT "ENTER THE START TIME",T1_calc
688      INPUT "ENTER THE END TIME",T2_calc
689    END IF
690    Rdg1=T1_calc*Scan_rate
691    Rdg2=T2_calc*Scan_rate
692    IF Rdg1=0 THEN Rdg1=1
693    IF Rdg2-Rdg1+1>2500 THEN Rdg2=Rdg1+2499
694    RETURN
695    !
696    !=====================================================
697 Base_calc:  !
698     !===================================================
699    FOR Chn=1 TO Nchns
700      Base_av=0
701      IF Ram$="RAM37" OR Ram$="RAM31" THEN
702        Base_counts=10
703      ELSE
704        Base_counts=100
```

```
705     END IF
706     FOR I=1 TO Base_counts
707       IF Ram$="RAM33" THEN
708         Base_av=Data(I+2350,Chn)+Base_av
709       ELSE
710         Base_av=Data(I,Chn)+Base_av
711       END IF
712     NEXT I
713     IF Ram$="RAM37" OR Ram$="RAM31" THEN
714       Base_l(Chn)=Base_av*.1
715     ELSE
716       Base_l(Chn)=Base_av*.01
717     END IF
718     IF Chn=27 THEN Base_l(Chn)=0  ! BASE LINE FOR SPEED LOG=0
719   NEXT Chn
720   RETURN
721   !================================================================
722 Calc_force:  !        FORCE TIME HISTORY CALCULATION
723   !==============================================================
724   DISP "CALCULATING BENDING MOMENT,SHEAR FORCE AND BOW FORCE"
725   T1=TIMEDATE
726   FOR Rdg=Rdg1 TO Rdg2
727 Calc_b: !    BENDING MOMENT CALCULATION FOR N FRAMES IN NEWTON*METERS
728   ! F 128
729     IF Ram$="RAM1" OR Ram$="RAM2" THEN
730       S01=(Data(Rdg,44)-Base_l(44))*S_e(2)*Calib(44)
731     ELSE
732       S01=.5*(Data(Rdg,44)-Base_l(44)+Data(Rdg,25)-Base_l(25))*S_e(2)
733     END IF
734     Bm(Rdg,2)=(S01)*E*Inertia(2)*D(2)
735   ! F 86
736     IF Ram$="RAM1" OR Ram$="RAM2" THEN
737       S01=.5*((Data(Rdg,43)-Base_l(43))*Calib(43)+(Data(Rdg,24)-Base_l(24))*
Calib(24))*S_e(3)
738     ELSE
739       S01=.5*(Data(Rdg,43)-Base_l(43)+Data(Rdg,24)-Base_l(24))*S_e(3)
740     END IF
741     Bm(Rdg,3)=(S01)*E*Inertia(3)*D(3)
742   ! F 55
743     IF Ram$="RAM1" OR Ram$="RAM2" THEN
744       S01=.5*((Data(Rdg,42)-Base_l(42))*Calib(42)+(Data(Rdg,23)-Base_l(23))*
Calib(23))*S_e(4)
745       S03=.5*((Data(Rdg,45)-Base_l(45))*Calib(45)+(Data(Rdg,46)-Base_l(46))*
Calib(46))*S_e(4)
746     ELSE
747       IF Ram$="RAM37" OR Ram$="RAM39" OR Ram$="RAM38" OR Ram$="RAM40" THEN
748         S01=(Data(Rdg,42)-Base_l(42))*S_e(4)
749       ELSE
750         S01=.5*(Data(Rdg,42)-Base_l(42)+Data(Rdg,23)-Base_l(23))*S_e(4)
751       END IF
752       S03=.5*(Data(Rdg,45)-Base_l(45)+Data(Rdg,46)-Base_l(46))*S_e(4)
753     END IF
754     Bm(Rdg,4)=(S01-S03)*E*Inertia(4)*D(4)
755   ! F 39
756     IF Ram$="RAM1" OR Ram$="RAM2" THEN
757       S01=.5*((Data(Rdg,22)-Base_l(22))*Calib(22)+(Data(Rdg,41)-Base_l(41))*
Calib(41))*S_e(5)
758     ELSE
759       IF VAL(Ram$[4,5])>=13 AND VAL(Ram$[4,5])<=22 THEN
760         S01=(Data(Rdg,22)-Base_l(22))*S_e(5)
```

```
761         ELSE
762           S01=.5*(Data(Rdg,22)-Base_l(22)+Data(Rdg,41)-Base_l(41))*S_e(5)
763         END IF
764       END IF
765   !   S03=Data(Rdg,26)-Base_l(26)
766       Bm(Rdg,5)=(S01)*E*Inertia(5)*D(5)
767     ! CF 44
768       IF Ram$="RAM1" OR Ram$="RAM2" THEN
769         S01=.5*((Data(Rdg,40)-Base_l(40))*Calib(40)+(Data(Rdg,21)-Base_l(21))*
Calib(21))*S_e(6)
770       ELSE
771         S01=.5*(Data(Rdg,40)-Base_l(40)+Data(Rdg,21)-Base_l(21))*S_e(6)
772 !     S03=Data(Rdg,12)-Base_l(12)
773       END IF
774       Bm(Rdg,6)=(S01)*E*Inertia(6)*D(6)
775     ! CF 35
776       IF Ram$="RAM1" OR Ram$="RAM2" THEN
777         S01=(Data(Rdg,20)-Base_l(20))*S_e(7)*Calib(20)
778       ELSE
779         S01=.5*(Data(Rdg,20)-Base_l(20)+Data(Rdg,39)-Base_l(39))*S_e(7)
780       END IF
781       IF Ram$="RAM39" THEN
782         S01=(Data(Rdg,20)-Base_l(20))*S_e(7)
783       END IF
784       Bm(Rdg,7)=(S01)*E*Inertia(7)*D(7)
785     ! CF 27
786       IF Ram$="RAM1" OR Ram$="RAM2" THEN
787         S01=.5*((Data(Rdg,38)-Base_l(38))*Calib(38)+(Data(Rdg,19)-Base_l(19))*
Calib(19))*S_e(8)
788       ELSE
789         IF VAL(Ram$[4,5])>=14 AND VAL(Ram$[4,5])<=22 THEN
790           S01=(Data(Rdg,19)-Base_l(19))*S_e(8)
791         ELSE
792           S01=.5*(Data(Rdg,19)-Base_l(19)+Data(Rdg,38)-Base_l(38))*S_e(8)
793         END IF
794       END IF
795       IF Ram$="RAM39" THEN
796         S01=(Data(Rdg,38)-Base_l(38))*S_e(8)
797       END IF
798       Bm(Rdg,8)=(S01)*E*Inertia(8)*D(8)
799     ! CF 17
800       IF Ram$="RAM1" OR Ram$="RAM2" THEN
801         S01=(Data(Rdg,18)-Base_l(18))*S_e(9)*Calib(18)
802       ELSE
803         IF Ram$="RAM14" OR Ram$="RAM15" OR Ram$="RAM26" OR Ram$="RAM29" OR Ram
$="RAM30" OR Ram$="RAM39" THEN
804           S01=(Data(Rdg,18)-Base_l(18))*S_e(9)
805         ELSE
806           S01=.5*(Data(Rdg,18)-Base_l(19)+Data(Rdg,37)-Base_l(37))*S_e(9)
807         END IF
808       END IF
809   !   S02=Data(Rdg,13)-Base_l(13)
810       Bm(Rdg,9)=(S01)*E*Inertia(9)*D(9)
811       !
812 Calc_sh:  !  SHEAR CALCULATION (NEWTONS)
813       !
814       FOR I=1 TO 9
815         Sh(Rdg,I+1)=-(Bm(Rdg,I+1)-Bm(Rdg,I))/(Loc_frame(I+1)-Loc_frame(I))
816       NEXT I
817       !
```

```
818 Calc_bf:  !  BOW FORCE CALCULATION  (NEWTONS)
819       !
820       Maxsh=Sh(Rdg,1)
821       Locsh=6
822       FOR K=6 TO 11
823         IF Sh(Rdg,K)<Maxsh THEN
824           Maxsh=Sh(Rdg,K)
825           Locsh=K
826         END IF
827       NEXT K
828       Possh=Sh(Rdg,Locsh)
829       FOR K=Locsh TO 11
830         IF Sh(Rdg,K)>Possh THEN
831           Possh=Sh(Rdg,K)
832         END IF
833       NEXT K
834       Bf(Rdg)=ABS(Maxsh)+Possh
835   !
836    NEXT Rdg
837    IF VAL(Ram$[4,5])>2 THEN
838      MAT Bf= Bf*(Calib(1))
839      MAT Bm= Bm*(Calib(1))
840      MAT Sh= Sh*(Calib(1))
841    END IF
842    T2=TIMEDATE
843    DISP "TIME TO CALCULATE BOW FORCE = ";T2-T1;" Sec."
844    BEEP
845    RETURN
846    !==========================================
847 Calc_max:  ! MAXIMUM SHEAR CALC AND TIME AT MAXIMUM SHEAR
848    !==========================================
849    T1=TIMEDATE
850    DISP "CALCULATING MAXIMUM BOW FORCE, BENDING MOMENT AND SHEAR FORCE"
851    Bff_max=MAX(Bff(*))
852    Sh_min=MIN(Sh(*))
853    Bm_min=MIN(Bm(*))
854    Bf_max=MAX(Bf(*))
855    Sh_max=MAX(Sh(*))
856    L_sh=10
857    L_bm=10
858    L_sh1=10
859    L_sh2=10
860    Speed=Data(Rdg1,27)
861    Bm5_min=Bm(1,5)
862    FOR Rdg=1 TO Nrdgs
863      IF Data(Rdg,27)>Speed THEN Speed=Data(Rdg,27)
864      IF Bm(Rdg,5)<Bm5_min THEN
865        Bm5_min=Bm(Rdg,5)
866        Tbm5=Rdg
867      END IF
868    NEXT Rdg
869    Tbm5=Tbm5/Scan_rate
870    Bm5_min=Bm5_min/(Inertia(5)*D(5))
871    !
872    FOR Rdg=Rdg1 TO Rdg2
873      FOR I=2 TO 9
874        IF Bm(Rdg,I)=Bm_min THEN
875          T_bm=Rdg
876          L_bm=I
877        END IF
```

```
878     NEXT I
879     IF Bf(Rdg)=Bf_max THEN T_bf=Rdg
880   NEXT Rdg
881   !
882   ! SHEAR AT TIME OF MAXIMUM BOW FORCE
883   Sh1=Sh(T_bf,1)
884   Sh2=Sh(T_bf,1)
885   FOR I=6 TO 11
886     IF Sh(T_bf,I)<Sh2 THEN
887       Sh2=Sh(T_bf,I)
888       L_sh2=I
889     END IF
890   NEXT I
891   FOR I=L_sh2 TO 10
892     IF Sh(T_bf,I)>=Sh1 THEN
893       Sh1=Sh(T_bf,I)
894       L_sh1=I
895     END IF
896   NEXT I
897   IF Sh1=0 THEN L_sh1=10
898   !
899   Speed=Speed*Calib(27)
900   Bf_max=Bf_max*1.E-6
901   Bm_min=Bm_min*1.E-6
902   Sh_min=Sh_min*1.E-6
903   Sh_max=Sh_max*1.E-6
904   Sh1=Sh1*1.E-6
905   Sh2=Sh2*1.E-6
906   T_bf=T_bf/Scan_rate
907   T_sh=T_sh/Scan_rate
908   T_sh1=T_sh1/Scan_rate
909   T_bm=T_bm/Scan_rate
910   !
911   T2=TIMEDATE
912   PRINT CHR$(12)
913   PRINT "TIME TO CALCULATE MAXIMUMS AND TIME OF OCCURANCE= ";T2-T1;" Sec."
914   GOSUB Disp_max
915   DISP "PUSH CONT"
916   BEEP
917   PRINT CHR$(12)
918   DISP ""
919   RETURN
920   !================
921 Disp_max:  !
922   !===============
923   PRINT ""
924   PRINT ""
925   PRINT USING Max_table;"BOW FORCE MAX  ";Bf_max;" MN   AT TIME ";T_bf;" sec
."
926   PRINT USING Max_table;"POS. SHEAR FORCE ";Sh1;" MN   AT TIME";T_bf;" sec."
;" LOC.= ";Fr$(L_sh1-1)&" TO "&Fr$(L_sh1)
927   PRINT USING Max_table;"NEG. SHEAR FORCE ";Sh2;" MN   AT TIME";T_bf;" sec."
;" LOC.= ";Fr$(L_sh2-1)&" TO "&Fr$(L_sh2)
928   PRINT USING Max_table;"MIN. SHEAR   ";Sh_min;" MN   AT TIME ";T_sh;" sec."
;" LOC.= ";Fr$(L_sh-1)&" TO "&Fr$(L_sh)
929   PRINT USING Max_table;"MAX. SHEAR    ";Sh_max;" MN   AT TIME ";T_sh1;" sec
.";" LOC.= ";Fr$(L_sh1-1)&" TO "&Fr$(L_sh1)
930   PRINT USING Max_table;"MAX. BEND. MOM.";Bm_min;" MNm  AT TIME ";T_bm;" sec
.";" LOC.= ";Fr$(L_bm)
931   PRINT "    MAXIMUM VELOCITY= ";Speed;" Knots"
```

```
932   RETURN
933   !=====================================================
934 Calc_loc:!
935   !=====================================================
936   DISP "CALCULATING THE LOCATION OF THE LOAD"
937   T1=TIMEDATE
938   Rdg=0
939   MAT Loc_load= (0)
940   !
941   FOR Rdg=Rdg1 TO Rdg2
942     Min_comp=(Data(Rdg,17)-Base_1(17))*Calib(17)
943     Loc_load(Rdg)=Long(17)
944     FOR Chn=16 TO 15 STEP -1
945       IF (Data(Rdg,Chn)-Base_1(Chn))*Calib(Chn)<Min_comp THEN
946         Min_comp=(Data(Rdg,Chn)-Base_1(Chn))*Calib(Chn)
947         Loc_load(Rdg)=Long(Chn)
948       END IF
949     NEXT Chn
950     FOR Chn=1 TO 8
951       IF (Data(Rdg,Chn)-Base_1(Chn))*Calib(Chn)<Min_comp THEN
952         Min_comp=(Data(Rdg,Chn)-Base_1(Chn))*Calib(Chn)
953         Loc_load(Rdg)=Long(Chn)
954       END IF
955     NEXT Chn
956   NEXT Rdg
957   !
958   BEEP
959   DISP ""
960   T2=TIMEDATE
961   DISP "LOCATION OF LOAD CALCULATION TIME= ";T2-T1
962   RETURN
963   !============
964 Order_loc:  !
965   !==============
966   DISP "SORTING LOAD LOCATION"
967   T1=TIMEDATE
968   Max_loc=MAX(Loc_load(*))
969   FOR K=Rdg1 TO Rdg2-1
970     IF Loc_load(K)>=Max_loc THEN
971       FOR I=1 TO K-1
972         Loc_load(I)=Loc_load(K)
973       NEXT I
974     END IF
975   NEXT K
976   FOR K=Rdg1 TO Rdg2-1
977     IF Loc_load(K+1)<Loc_load(K) THEN
978       Down_flg=1
979       I=K
980     END IF
981     IF Loc_load(K+1)>Loc_load(K) THEN
982       FOR N=I+1 TO K
983         Loc_load(N)=Loc_load(I)
984       NEXT N
985     END IF
986   NEXT K
987   DISP ""
988   T2=TIMEDATE
989   DISP "CALCULAION TO SORT LOAD LOCATION TIME= ";T2-T1
990   BEEP
991   RETURN
```

```
992   !=================================================================
993 Plot_data: !
994   !=================================================================
995   GOSUB Default_scales
996   !
997  ! **********************************************************************
998  ! GRAPHICS KEYS
999  ! **********************************************************************
1000 Graphics_keys: !
1001              !
1002  Title$="RAM #"&Ram$[4,6]
1003  OFF KEY
1004  ON KEY 0 LABEL "NEW PLOT",1 GOSUB New_plot
1005  ON KEY 5 LABEL "ADD CHAN",1 GOSUB Add_chan
1006  ON KEY 1 LABEL "NEW XSCALE",1 GOSUB New_xscale
1007  ON KEY 6 LABEL "NEW YSCALE",1 GOSUB New_yscale
1008  ON KEY 2 LABEL "ALL CHAN ",1 GOTO All_chan
1009  ON KEY 7 LABEL "PLOT CALC",1 GOTO Plot_calc
1010  ON KEY 3 LABEL "REF LINE",1 GOSUB Ref_line
1011  ON KEY 8 LABEL "PEN PLOTTER",1 GOSUB Pen_plot
1012  ON KEY 4 LABEL "DUMP GRAPHICS",1 GOSUB Dump_graphics
1013  ON KEY 9 LABEL "RETURN",1 GOTO Exit_graphics
1014 Stay_plot:GOTO Stay_plot
1015  !
1016  !===================
1017 Pen_plot: !
1018  Pen_flg=-Pen_flg
1019  Grid_flg=-Grid_flg
1020  BEEP
1021  RETURN
1022  !==============
1023 Ref_line: !
1024  !==============
1025  BEEP
1026  Ref_flg=-Ref_flg
1027  Refl=T
1028  RETURN
1029  !========================================
1030 Plot_calc: !
1031  !========================================
1032              !
1033  Grid_flg=1
1034 !
1035  DUMP DEVICE IS 701
1036  OFF KEY
1037  ON KEY 5 LABEL "BEND/SH",1 GOTO P_bsh
1038  ON KEY 6 LABEL "PLOT SUMM ",1 GOTO P_sum_calc
1039  ON KEY 7 LABEL "BOW FORCE",1 GOTO P_bf
1040  ON KEY 8 LABEL "LOC LOAD",1 GOTO P_loc
1041  ON KEY 9 LABEL "RETURN",1 GOTO Lp_calc
1042  ON KEY 0 LABEL "CHANGE SCALES",1 GOTO New_cscale
1043  ON KEY 1 LABEL "N. AXIS",1 GOTO P_n
1044  ON KEY 2 LABEL "ANIMATE",1 GOSUB Animate
1045  ON KEY 3 LABEL "STEP ",1 GOSUB Step
1046  ON KEY 4 LABEL "PEN PLOTTER",1 GOSUB Pen_plot
1047 Stay_p:GOTO Stay_p
1048 Lp_calc: !
1049  Bf_flg=0
1050  Bm_flg=0
1051  Sh_flg=0
```

```
1052  GOTO Plot_data
1053  !
1054  !========================================================
1055 P_bsh: !
1056  !========================================================
1057  ON KEY 5 LABEL "BEND",1 GOTO P_bm
1058  ON KEY 6 LABEL "SHEAR",1 GOTO P_sh
1059  ON KEY 7 LABEL "CUBIC SPLINE",1 GOTO P_cub_spl
1060  ON KEY 8 LABEL "SHEAR CURVE",1 GOTO P_sh_curve
1061  ON KEY 9 LABEL "RETURN",1 GOTO Plot_calc
1062  ON KEY 0 LABEL "CHANGE SCALES",1 GOTO New_cscale
1063  ON KEY 1 LABEL "PEN PLOTTER",1 GOSUB Pen_plot
1064  ON KEY 2 LABEL "ANIMATE",1 GOSUB Animate
1065  ON KEY 3 LABEL "STEP ",1 GOSUB Step
1066  ON KEY 4 LABEL "DUMP GRAPHICS",1 GOSUB Dump_graphics
1067 Wait_pbs:GOTO Wait_pbs
1068  !
1069  !==================================
1070 P_cub_spl: !
1071  !==================================
1072  MAT Xx= (0)
1073  MAT Yy= (0)
1074! DISP "CUBIC SPLINE ROUTINE"
1075 !INPUT "ENTER THE STARTING POINT FOR CUBIC SPLINE INTERPOLATION",St_cub
1076  St_cub=1
1077  K=0
1078  !
1079  IF Bm_flg=1 THEN
1080    FOR I=St_cub TO 10
1081      K=K+1
1082      Xx(K)=Loc_frame(I)
1083      Yy(K)=Bm(Rdg,I)
1084    NEXT I
1085    Npts=K
1086  END IF
1087  !
1088  K=0
1089  IF Sh_flg=1 THEN
1090    FOR I=St_cub TO 11
1091      K=K+1
1092      Xx(K)=Sh_frame(I)
1093      Yy(K)=Sh(Rdg,I)
1094    NEXT I
1095    Npts=K
1096  END IF
1097  !
1098  GOSUB Cubic_spline
1099  GOTO P_bsh
1100  !=============
1101 P_n: !
1102  !=============
1103  INPUT "ENTER THE FRAME TO PLOT (55,39,CF44,CF35,CF27,CF17)",Nfr$
1104  IF Nfr$="55" THEN
1105    Nfr=1
1106    Nfr$="FRAME 55"
1107  END IF
1108  IF Nfr$="39" THEN
1109    Nfr=2
1110    Nfr$="FRAME 39"
1111  END IF
```

```
1112  IF Nfr$="CF44" THEN Nfr=3
1113  IF Nfr$="CF35" THEN Nfr=4
1114  IF Nfr$="CF27" THEN Nfr=5
1115  IF Nfr$="CF17" THEN Nfr=6
1116  IF Nfr<1 OR Nfr>6 THEN GOTO P_n
1117  N_flg=1
1118  Title$="NEUTRAL AXIS LOCATION: "&Nfr$&"  RAM #"&Ram$[4,6]
1119  X_unit$="Sec."
1120  Y_unit$="m"
1121  X_title$="TIME "
1122  Y_title$="NEUTRAL AXIS LOC."
1123  Xmin=T1_calc
1124  Xmax=T2_calc
1125  Ymin=-5
1126  Ymax=20
1127 P_n1: !
1128  GOSUB Find_scale
1129  GOSUB Plot_frame
1130  !
1131  IF Xmin=0 THEN Xmin=1/Scan_rate
1132  Rdg1=Xmin*Scan_rate
1133  Rdg2=Xmax*Scan_rate
1134  MOVE Rdg1/Scan_rate,Neut(Rdg1,Nfr)
1135  FOR Rdg=Rdg1 TO Rdg2
1136    IF Neut(Rdg,Nfr)<Ymax AND Neut(Rdg,Nfr)>Ymin THEN PLOT Rdg/Scan_rate,Neu
t(Rdg,Nfr),-1
1137  NEXT Rdg
1138 Wait_n:GOTO Wait_n
1139  GOTO Plot_calc
1140  !=================
1141  !==============
1142  !===================
1143 P_loc: !
1144  !===================
1145  !
1146  Xmax=T2_calc
1147  Xmin=T1_calc
1148  Ymin=90
1149  Ymax=130
1150  L_flg=1
1151  Bf_flg=0
1152  Sh_flg=0
1153  Step_flg=-1
1154  Anim_flg=-1
1155 P_loc1: !
1156  INPUT "DO YOU WANT TO PLOT THE DISTRIBUTION OF LOC STRESSES",Q$
1157  IF Q$="Y" THEN
1158    GOTO P_ploc_an
1159  END IF
1160  GOSUB Pl_graph
1161  GOSUB Pl_pts
1162  DISP "PUSH CONT"
1163  PAUSE
1164  DISP ""
1165  GRAPHICS OFF
1166  Q$=""
1167  INPUT "DO YOU WANT TO DISPLAY LOCATION OF LOAD IN BENDING AND SHEAR PLOTS
(Y,N)",Q$
1168  IF Q$="Y" THEN
1169    Loc_flg=1
```

```
1170  ELSE
1171    Loc_flg=0
1172  END IF
1173  GOTO Plot_calc
1174  !
1175  !==============
1176 P_ploc_an: !
1177  !================
1178  !
1179  INPUT "ENTER THE TIME TO START ANIMATION",T1
1180  INPUT "DO YOU WANT TO ERASE EACH  LINE",Er_$
1181  Rdg1=T1*Scan_rate
1182  Xmin=100
1183  Xmax=120
1184  IF Unit$(1)="Pa." THEN
1185    Ymin=-50
1186    Ymax=52
1187  ELSE
1188    Ymin=-40
1189    Ymax=40
1190  END IF
1191  !
1192  Title$="STRESS ALONG CENTRE LINE WEB"
1193  X_title$="DISTANCE FROM AFT END"
1194  Y_title$="MEASURED STRESS"
1195  X_unit$="m"
1196  Y_unit$="MPa"
1197  GOSUB Find_scale
1198  GOSUB Plot_frame
1199  GOSUB Label_frames
1200  !
1201  LORG 2
1202  MOVE 115,5
1203  LABEL "TENSION"
1204  MOVE 115,-5
1205  LABEL "COMPRESSION"
1206  PEN 1
1207  IF Pen_flg=-1 AND Er_$="Y" THEN PEN 0
1208  PEN 1
1209  E_f=2.07E+5
1210  !
1211  MOVE Long(8),(Data(Rdg1,8)-Base_1(8))*Calib(8)*E_f
1212  FOR Chn=2 TO 8
1213    PLOT Long(9-Chn),(Data(Rdg1,9-Chn)-Base_1(9-Chn))*Calib(9-Chn)*E_f,-1
1214  NEXT Chn
1215    !
1216  PLOT Long(15),(Data(Rdg1,15)-Base_1(15))*Calib(15)*E_f,-1
1217  PLOT Long(16),(Data(Rdg1,16)-Base_1(16))*Calib(16)*E_f,-1
1218  PLOT Long(17),(Data(Rdg1,17)-Base_1(17))*Calib(17)*E_f,-1
1219    !
1220  IF Pen_flg=1 THEN
1221    LORG 2
1222    CSIZE C_size
1223    MOVE Xmin+.1*(Xmax-Xmin),.8*Ymin
1224    LABEL "TIME=";Rdg1/Scan_rate;" sec."
1225    !
1226  END IF
1227  IF Pen_flg=1 THEN GOTO Plot_calc
1228    !
1229  FOR Rdg=Rdg1+1 TO Rdg2
```

```
1230  !
1231    MOVE Long(8),(Data(Rdg-1,8)-Base_1(8))*Calib(8)*E_f
1232    FOR Chn=2 TO 8
1233      PLOT Long(9-Chn),(Data(Rdg-1,9-Chn)-Base_1(9-Chn))*Calib(9-Chn)*E_f,-1
1234    NEXT Chn
1235    !
1236    PLOT Long(15),(Data(Rdg-1,15)-Base_1(15))*Calib(15)*E_f,-1
1237    PLOT Long(16),(Data(Rdg-1,16)-Base_1(16))*Calib(16)*E_f,-1
1238    PLOT Long(17),(Data(Rdg-1,17)-Base_1(17))*Calib(17)*E_f,-1
1239      !
1240    MOVE Long(8),(Data(Rdg,8)-Base_1(8))*Calib(8)*E_f
1241    FOR Chn=2 TO 8
1242      PLOT Long(9-Chn),(Data(Rdg,9-Chn)-Base_1(9-Chn))*Calib(9-Chn)*E_f,-1
1243    NEXT Chn
1244    PLOT Long(15),(Data(Rdg,15)-Base_1(15))*Calib(15)*E_f,-1
1245    PLOT Long(16),(Data(Rdg,16)-Base_1(16))*Calib(16)*E_f,-1
1246    PLOT Long(17),(Data(Rdg,17)-Base_1(17))*Calib(17)*E_f,-1
1247    !
1248    IF Er_$="Y" THEN DISP "                          TIME= ";Rdg/Scan_rate
1249 Idle_1:   !
1250    IF Step_flg<>1 THEN
1251      IF Anim_flg=1 THEN GOTO Next_rdg1
1252      GOTO Idle_1
1253    ELSE
1254      Step_flg=-Step_flg
1255    END IF
1256    !
1257 Next_rdg1:   !
1258  NEXT Rdg
1259  GOTO Plot_calc
1260  RETURN
1261  !==============
1262 Pl_graph: !
1263  !============
1264  Title$="LOCATION OF CENTRE OF LOAD RAM "&Ram$[4,5]
1265  X_title$="TIME"
1266  Y_title$="LOAD LOCATION"
1267  X_unit$="Sec."
1268  Y_unit$="m"
1269  GOSUB Find_scale
1270  GOSUB Plot_frame
1271  RETURN
1272  !=============
1273 Pl_pts: !
1274  !==============
1275  IF Xmin=0 THEN Xmin=1/Scan_rate
1276  MOVE Xmin,Loc_load(1)
1277  FOR Rdg=Xmin*Scan_rate TO Xmax*Scan_rate
1278    PLOT Rdg/Scan_rate,Loc_load(Rdg),-1
1279  NEXT Rdg
1280  LORG 2
1281  CLIP OFF
1282  FOR I=1 TO 10
1283    MOVE Xmax+.03*Xscale,Loc_frame(I)
1284    LABEL USING "K";Fr$(I)
1285  NEXT I
1286  CLIP ON
1287  RETURN
1288  !=======================
1289 New_cscale: !  NEW  X SCALES
```

```
1290  !========================
1291  INPUT "ENTER NEW XMIN OR PUSH CONT FOR DEFAULT VALUES",Xmin
1292  INPUT "ENTER NEW XMAX OR PUSH CONT FOR DEFAULT VALUES",Xmax
1293  !===========================
1294 ! New_cscale: !  NEW Y SCALES
1295  !=============================
1296  INPUT "ENTER NEW YMIN OR PUSH CONT FOR DEFAULT VALUES",Ymin
1297  INPUT "ENTER NEW YMAX OR PUSH CONT FOR DEFAULT VALUES",Ymax
1298  IF Sh_flg OR Bm_flg OR Bf_flg THEN
1299    IF Ymax<2000 THEN
1300      Ymin=Ymin*1.E+6
1301      Ymax=Ymax*1.E+6
1302    END IF
1303  END IF
1304  !
1305  FOR I=1 TO 8
1306    IF Bs_loc(I)>=Xmin THEN
1307      Fr1=I
1308      GOTO Cont_n
1309    END IF
1310  NEXT I
1311 Cont_n: !
1312  IF Bm_flg THEN GOTO P_bm1
1313  IF Sh_flg THEN GOTO P_sh1
1314  IF Bf_flg THEN GOTO P_bf1
1315  IF N_flg THEN GOTO P_n1
1316  IF L_flg=1 THEN GOTO P_loc1
1317  !
1318  GOTO Plot_calc
1319  !==============
1320 Animate: !
1321  !===============
1322  Anim_flg=-Anim_flg
1323  RETURN
1324  !==================
1325 Step: !
1326  !===================
1327  Step_flg=1
1328  RETURN
1329  !
1330  !=====================================
1331 P_sr: !
1332  !==================================
1333  GOSUB Sr_graph
1334  GOSUB Sr_pts
1335  GOTO Plot_calc
1336  !
1337  !===============
1338 Sr_graph: !
1339  !==================
1340  X_title$="DISTANCE FROM AFT END"
1341  Y_title$="STRAIN RATIO"
1342  X_unit$="m"
1343  Y_unit$="strain"
1344  Xmin=50
1345  Xmax=150
1346  Ymin=-3
1347  Ymax=3
1348  GOSUB Find_scale
1349  GOSUB Plot_frame
```

```
1350  GOSUB Label_frames
1351  RETURN
1352  !==============================================
1353 Bm_scale:!
1354  !==============================================
1355  Xmin=0
1356  Xmax=150
1357  Ymin=-3.00E+8
1358  Ymax=1.00E+8
1359  Frl=1
1360  Pfrm=10
1361  RETURN
1362  !==============================================
1363 Sh_scale:!
1364  !==============================================
1365  Xmin=0
1366  Xmax=150
1367  Ymin=-2.5E+7
1368  Ymax=1.5E+7
1369  Frl=1
1370  Pfrm=11
1371  RETURN
1372  !===================================
1373 P_bm: !
1374 !==============================
1375  INPUT "ENTER THE FIRST TIME FOR BENDING MOMENT DISPLAY (Sec.)",Bmt
1376  Bmt=Bmt*Scan_rate
1377! IF Bmt>Rdg2 OR Bmt<Rdg1 THEN GOTO P_bm
1378  Rdg1=Bmt
1379  Rdg2=Nrdgs
1380  GOSUB Bm_scale
1381  !
1382 P_bm1: !
1383  L_flg=0
1384  Bm_flg=1
1385  Sh_flg=0
1386  Step_flg=-1
1387  Anim_flg=-1
1388  GOSUB B_graph
1389  IF Pen_flg=-1 THEN
1390    GOSUB P_pbm
1391  ELSE
1392    GOSUB P_bpts
1393  END IF
1394  MOVE Xmin+(Xmax-Xmin)*.01,Ymin+(Ymax-Ymin)*.9
1395  LORG 2
1396  CLIP OFF
1397  IF Pen_flg=1 THEN LABEL "   TIME= "&VAL$(Rdg/Scan_rate)&" sec."
1398  CLIP ON
1399  DISP "PUSH CONT"
1400  PAUSE
1401  DISP ""
1402  GRAPHICS OFF
1403  GOTO Plot_calc
1404  !
1405  !==============
1406 B_graph:          !
1407  !===============
1408  Title$="BENDING MOMENT DIAGRAM  RAM "&Ram$[4,6]
1409  X_title$="DISTANCE FROM AFT END"
```

```
1410  Y_title$="BENDING MOMENT"
1411  X_unit$="m"
1412  Y_unit$="Nm"
1413  GOSUB Find_scale
1414  GOSUB Plot_frame
1415  GOSUB Label_frames
1416  !
1417  RETURN
1418  !====================================
1419 P_sh: !
1420 !================================
1421  INPUT "ENTER THE FIRST TIME FOR SHEAR DIAGRAM DISPLAY (Sec.)",Sht
1422  Rdg1=Sht*Scan_rate
1423  Bm_flg=0
1424  Sh_flg=1
1425  Step_flg=-1
1426  Anim_flg=-1
1427  GOSUB Sh_scale
1428 P_sh1: !
1429  GOSUB Sh_graph
1430  IF Pen_flg=1 THEN
1431    GOSUB P_pshpts
1432  ELSE
1433    GOSUB P_shpts
1434  END IF
1435  !
1436  PEN 1
1437  MOVE Xmin+(Xmax-Xmin)*.01,.3*Ymin
1438  LORG 2
1439  CLIP OFF
1440 !IF Pen_flg=1 THEN LABEL "   TIME= "&VAL$(Rdg/Scan_rate)&" sec."
1441  !
1442  CLIP ON
1443  DISP "PUSH CONT"
1444  PAUSE
1445  DISP ""
1446  GRAPHICS OFF
1447  GOTO Plot_calc
1448  !
1449  !===================
1450 P_bpts: !
1451  !================
1452  !
1453  PEN 0
1454  IF Loc_flg THEN
1455    MOVE Loc_load(Rdg1),Ymin
1456    PLOT Loc_load(Rdg1),Ymax,-1
1457  END IF
1458  !
1459  MOVE Loc_frame(Fr1),Bm(Rdg1,Fr1)
1460  FOR I=Fr1 TO 10
1461    PLOT Loc_frame(I),Bm(Rdg1,I),-1
1462  NEXT I
1463  !
1464  !
1465  FOR Rdg=Rdg1+1 TO Rdg2
1466    IF Loc_flg THEN
1467      MOVE Loc_load(Rdg-1),Ymin
1468      PLOT Loc_load(Rdg-1),Ymax,-1
1469    END IF
```

```
1470    MOVE Loc_frame(Fr1),Bm(Rdg-1,Fr1)
1471    FOR I=Fr1 TO 10
1472      PLOT Loc_frame(I),Bm(Rdg-1,I),-1
1473    NEXT I
1474    IF Loc_flg THEN
1475      MOVE Loc_load(Rdg),Ymin
1476      PLOT Loc_load(Rdg),Ymax,-1
1477    END IF
1478    !
1479    MOVE Loc_frame(Fr1),Bm(Rdg,Fr1)
1480    FOR I=Fr1 TO 10
1481      PLOT Loc_frame(I),Bm(Rdg,I),-1
1482    NEXT I
1483    IF Pen_flg=-1 THEN DISP "                                         TIME= ";Rdg/Scan_r
ate
1484      !
1485 Idle:ENABLE
1486    IF Step_flg<>1 THEN
1487      IF Anim_flg=1 THEN GOTO Next_rdg
1488      GOTO Idle
1489    ELSE
1490      Step_flg=-Step_flg
1491    END IF
1492 Next_rdg:NEXT Rdg
1493      !
1494  Position=Xmin
1495  Curs_flg=0
1496  !
1497  RETURN
1498  !
1499  !======================
1500 P_pbm: !
1501  !======================
1502  FOR Ii=1 TO 3
1503    IF Ii=1 THEN Rdg=10*Scan_rate
1504    IF Ii=2 THEN Rdg=10.2*Scan_rate
1505    IF Ii=3 THEN Rdg=10.3*Scan_rate
1506    PEN 1
1507    MOVE Loc_frame(Fr1),Bm(Rdg,Fr1)
1508    FOR I=Fr1 TO 10
1509      PLOT Loc_frame(I),Bm(Rdg,I),-1
1510    NEXT I
1511  !
1512    LORG 5
1513    CSIZE C_size*2.0
1514    MOVE Loc_frame(Fr1),Bm(Rdg,Fr1)
1515    FOR I=Fr1 TO 10
1516      MOVE Loc_frame(I),Bm(Rdg,I)
1517    LABEL USING "K";"+"
1518    NEXT I
1519  NEXT Ii
1520  CSIZE C_size
1521  RETURN
1522  !
1523  !==================
1524 P_shpts:!
1525  !===============
1526  !
1527  PEN 0
1528  IF Loc_flg THEN
```

```
1529    MOVE Loc_load(Rdg1),Ymin
1530    PLOT Loc_load(Rdg1),Ymax,-1
1531  END IF
1532  MOVE Loc_frame(Fr1),Sh(Rdg1,Fr1)
1533  FOR I=Fr1 TO 11
1534    PLOT Sh_frame(I),Sh(Rdg1,I),-1
1535  NEXT I
1536  FOR Rdg=Rdg1+1 TO Rdg2
1537    IF Loc_flg THEN
1538      MOVE Loc_load(Rdg-1),Ymin
1539      PLOT Loc_load(Rdg-1),Ymax,-1
1540    END IF
1541    MOVE Sh_frame(Fr1),Sh(Rdg-1,Fr1)
1542    FOR I=Fr1 TO 11
1543      PLOT Sh_frame(I),Sh(Rdg-1,I),-1
1544    NEXT I
1545    IF Loc_flg THEN
1546      MOVE Loc_load(Rdg),Ymin
1547      PLOT Loc_load(Rdg),Ymax,-1
1548    END IF
1549    MOVE Sh_frame(Fr1),Sh(Rdg,Fr1)
1550    FOR I=Fr1 TO 11
1551      PLOT Sh_frame(I),Sh(Rdg,I),-1
1552    NEXT I
1553    DISP "                             TIME= ";Rdg/Scan_rate
1554    !
1555    LORG 5
1556    CSIZE C_size*2.0
1557    MOVE Sh_frame(Fr1),Sh(Rdg,Fr1)
1558    FOR I=Fr1 TO 10
1559      MOVE Sh_frame(I),Sh(Rdg,I)
1560    ! LABEL USING "K";"+"
1561    NEXT I
1562    CSIZE C_size
1563      !
1564 Idle_sh:ENABLE
1565    IF Step_flg<>1 THEN
1566      IF Anim_flg=1 THEN GOTO Next_shrdg
1567      GOTO Idle_sh
1568    ELSE
1569      Step_flg=-Step_flg
1570    END IF
1571 Next_shrdg:NEXT Rdg
1572      !
1573  Position=Xmin
1574  Curs_flg=0
1575  !
1576  RETURN
1577  !
1578  !======================
1579 P_pshpts: !
1580  !======================
1581  Rdg=Rdg1
1582  IF Loc_flg THEN
1583    MOVE Loc_load(Rdg),0
1584    PLOT Loc_load(Rdg),.8*Ymin,-1
1585    MOVE Loc_load(Rdg),.85*Ymin
1586    LORG 2
1587    LABEL USING "K";"LOAD CENTRE"
1588  END IF
```

```
1589  !
1590  PEN 1
1591  MOVE Sh_frame(Fr1),Sh(Rdg,Fr1)
1592  FOR I=Fr1 TO 11
1593    PLOT Sh_frame(I),Sh(Rdg,I),-1
1594      !
1595  NEXT I
1596  PEN 1
1597  !
1598  LORG 5
1599  CSIZE C_size*2.0
1600  MOVE Sh_frame(Fr1),Sh(Rdg,Fr1)
1601  FOR I=Fr1 TO 10
1602    MOVE Sh_frame(I),Sh(Rdg,I)
1603    LABEL USING "K";"+"
1604  NEXT I
1605  CSIZE C_size
1606! NEXT Ii
1607  !
1608  RETURN
1609  !========================================
1610 Sh_graph:!
1611  !========================================
1612  !
1613  Title$="SHEAR DIAGRAM RAM "&Ram$[4,6]
1614  Y_title$="SHEAR"
1615  X_title$="DISTANCE FROM AFT END"
1616  X_unit$="m"
1617  Y_unit$="N"
1618  GOSUB Find_scale
1619  GOSUB Plot_frame
1620  GOSUB Label_frames
1621  RETURN
1622  !
1623  !==========================================
1624 Bf_scale:!    PLOT BOW FORCE DIAGRAM
1625  !==========================================
1626  Title$="BOW FORCE TIME HISTORY  RAM "&Ram$[4,6]
1627  X_title$="TIME"
1628  X_unit$="sec"
1629  Y_unit$="N"
1630  Bf_flg=1
1631  Xmin=T1_calc
1632  Xmax=T2_calc
1633  Ymin=0
1634  Ymax=3.0E+7
1635  RETURN
1636  !=====================
1637 P_bf: !
1638  !======================
1639  Bf_flg=1
1640  Sh_flg=0
1641  Bm_flg=0
1642  GOSUB Bf_scale
1643 P_bf1:!
1644  GOSUB Find_scale
1645    Y_title$="VERTICAL BOW FORCE"
1646  GOSUB Plot_frame
1647  GOSUB Pbf_pts
1648  IF Pen_flg=1 THEN PRINT "SP"
```

```
1649  IF Auto_flg=1 THEN RETURN
1650  GOTO Plot_calc
1651  !
1652  !=================
1653 Pbf_pts: !
1654  !==============
1655  IF Bf$<>"F" THEN
1656    MOVE Xmin*Scan_rate/Scan_rate,Bf(1)
1657    FOR Rdg=Xmin*Scan_rate TO Xmax*Scan_rate
1658      IF Rdg=0 THEN Rdg=1
1659      PLOT Rdg/Scan_rate,Bf(Rdg),-1
1660    NEXT Rdg
1661  ELSE
1662  !
1663    MOVE Xmin*Scan_rate/Scan_rate,Bff(1)
1664    FOR Rdg=Xmin*Scan_rate TO Xmax*Scan_rate
1665      IF Rdg=0 THEN Rdg=1
1666      PLOT Rdg/Scan_rate,Bff(Rdg),-1
1667    NEXT Rdg
1668  END IF
1669  RETURN
1670  !
1671    !=====================================================
1672 Re_scale:   !
1673    !================================================
1674  IF Unit$(Chn)="strain" THEN
1675    Ymax=Old_ymax
1676    Ymin=Old_ymin
1677    Xmax=Old_xmax
1678    Xmin=Old_xmin
1679  END IF
1680      !
1681  IF Unit$(Chn)="g" THEN
1682    Ymax=10
1683    Ymin=-10
1684  ELSE
1685    IF Unit$(Chn)="knots" THEN
1686      Ymax=15
1687      Ymin=0
1688    END IF
1689  END IF
1690  RETURN
1691   !=========================================================
1692 New_plot:   !
1693  GOSUB Select_chan
1694  GOSUB Re_scale
1695  GOSUB Plot_graph
1696  RETURN
1697   !
1698   !==========================================================
1699 Add_chan:  !
1700  GOSUB Select_chan
1701  GOSUB Re_scale
1702  GOSUB Plot_pts
1703  RETURN
1704    !
1705    !=======================
1706 All_chan:   !
1707  Chn=0
1708  X_unit$="Sec."
```

```
1709  X_title$="TIME"
1710  ON KEY 0 LABEL "",1 GOTO Wait_all
1711  ON KEY 1 LABEL "NEW XSCALE",1 GOSUB New_xscale
1712  ON KEY 2 LABEL "",1 GOTO Wait_all
1713  ON KEY 3 LABEL "",1 GOTO Wait_all
1714  ON KEY 4 LABEL "REPORT",1 GOTO Report
1715  ON KEY 5 LABEL "NEXT CHAN",1 GOSUB Next_chan
1716  ON KEY 6 LABEL "NEW YSCALE",1 GOSUB New_yscale
1717  ON KEY 7 LABEL "",1 GOTO Wait_all
1718  ON KEY 8 LABEL "",1 GOTO Wait_all
1719  ON KEY 9 LABEL "RETURN  ",1 GOTO Plot_data
1720 Wait_all:GOTO Wait_all
1721     !
1722     !======================
1723 Report:   !
1724     !======================
1725  Rep_flg=1
1726  DUMP DEVICE IS 701
1727  Q$=""
1728  INPUT "DO YOU WANT A HARD COPY (Y,N)",Dump$
1729  FOR I=1 TO 3
1730    Group$(I)=""
1731    INPUT "ENTER THE GROUP TO PRINT (B,C,M) OR PUSH CONT",Group$(I)
1732  NEXT I
1733 !FOR Ram_r=2 TO 26
1734  !IF Ram_r=1 THEN Ram_no=2
1735  IF Ram_r=2 THEN Ram_no=4
1736  IF Ram_r=3 THEN Ram_no=6
1737  IF Ram_r=4 THEN Ram_no=7
1738  IF Ram_r=5 THEN Ram_no=8
1739  IF Ram_r=6 THEN Ram_no=13
1740  IF Ram_r>6 THEN Ram_no=Ram_r+8
1741 !GOSUB Read_data
1742! Title$="RAM"&VAL$(Ram_no)
1743  FOR Rep=1 TO 3
1744    IF Group$(Rep)="B" THEN GOSUB R_1
1745    IF Group$(Rep)="C" THEN GOSUB R_2
1746    IF Group$(Rep)="M" THEN GOSUB R_3
1747  NEXT Rep
1748 !NEXT Ram_r
1749  GRAPHICS OFF
1750  GOTO All_chan
1751  !============
1752 R_1: !
1753  !============
1754  R_plot=0
1755  !DECK 01
1756  FOR Chn=18 TO 25
1757    GOSUB Next_rp
1758  NEXT Chn
1759  FOR Chn=37 TO 44
1760    GOSUB Next_rp
1761  NEXT Chn
1762  ! DECK 2
1763  Chn=13
1764  GOSUB Next_rp
1765  ! DECK 3
1766  FOR Chn=11 TO 12
1767    GOSUB Next_rp
1768  NEXT Chn
```

```
1769  Chn=26
1770  GOSUB Next_rp
1771  FOR Chn=45 TO 46
1772    GOSUB Next_rp
1773  NEXT Chn
1774  Chn=36
1775  GOSUB Next_rp
1776  FOR Chn=9 TO 10
1777    GOSUB Next_rp
1778  NEXT Chn
1779  GOSUB Dump_spec
1780  RETURN
1781 !============
1782 R_2:!
1783 !=============
1784  R_plot=0
1785  FOR Chn=17 TO 15 STEP -1
1786    GOSUB Next_rp
1787  NEXT Chn
1788  FOR Chn=1 TO 8
1789    GOSUB Next_rp
1790  NEXT Chn
1791  FOR Chn=31 TO 35
1792    Ymin=-5.00E-4
1793    Ymax=4.00E-4
1794    GOSUB Next_rp
1795  NEXT Chn
1796  RETURN
1797  !===============
1798 R_3: !
1799  !===============
1800  R_plot=0
1801  Chn=27
1802  Xmin=0
1803  Xmax=25
1804  Ymin=0
1805  Ymax=15
1806  GOSUB Next_rp
1807  Ymin=-1
1808  Ymax=1
1809  FOR Chn=28 TO 30
1810    GOSUB Next_rp
1811  NEXT Chn
1812  RETURN
1813 !===============
1814 Next_rp:!
1815 !===============
1816  Y_title$=Id$(Chn)
1817  Y_unit$=Unit$(Chn)
1818  IF Chn<31 AND Chn>35 THEN
1819    IF Chn<>27 THEN
1820      GOSUB Re_scale
1821    END IF
1822  END IF
1823  GOSUB Plot_graph
1824  IF Dump$="Y" THEN GOSUB Dump_r
1825  RETURN
1826 !=====================
1827 Dump_r:     !
1828 !===================
1829  R_plot=R_plot+1
1830  DUMP GRAPHICS
1831  PRINTER IS 701
1832  PRINT ""
1833  PRINT ""
1834  IF R_plot MOD 2<=0 AND R_plot<>1 THEN GOSUB Dump_spec
1835  RETURN
1836    !============
1837 Next_chan: !
1838    !============
1839  Chn=Chn+1
1840  IF Chn>Nchns OR Chn<0 THEN Chn=1
1841  Y_title$=Id$(Chn)
1842  Y_unit$=Unit$(Chn)
1843  GOSUB Re_scale
1844  GOSUB Plot_graph
1845  RETURN
1846  !
1847  !===============================================================
1848 Select_chan:!
1849  !===============================================================
1850  INPUT "ENTER THE CHANNEL ID TO PLOT",Chan_id$
1851  GOSUB Find_chan
1852  X_title$="TIME"
1853  Y_title$=Id$(Chn)
1854  Y_unit$=Unit$(Chn)
1855  X_unit$="Sec."
1856  INPUT "ENTER THE Y AXIS TITLE",Y_title$
1857  INPUT "ENTER THE GRAPH TITLE",Title$
1858  DISP ""
1859  RETURN
1860  !
1861  !=========================================================
1862 Find_chan: !
1863  !=========================================================
1864  FOR Chn=1 TO Nchns
1865    IF Chan_id$=Id$(Chn) THEN RETURN
1866  NEXT Chn
1867  FOR Chn=1 TO Nchns
1868    IF Chan_id$=VAL$(Chn) THEN RETURN
1869  NEXT Chn
1870  BEEP
1871  INPUT "CHANNEL ID NOT FOUND RE-ENTER CHANNEL ID",Chan_id$
1872  GOTO Find_chan
1873 !
1874 !==========================================================
1875 Plot_graph:   !
1876 !==========================================================
1877  IF Chn<=0 THEN GOSUB Select_chan
1878  IF Unit$(Chn)="strain" THEN
1879    Old_ymin=Ymin
1880    Old_ymax=Ymax
1881    Old_xmin=Xmin
1882    Old_xmax=Xmax
1883  END IF
1884  GOSUB Find_scale
1885  GOSUB Plot_frame
1886  GOSUB Plot_pts
1887  RETURN
1888  !
```

```
1889  !=========================================================
1890 New_yscale: !
1891  !=========================================================
1892  IF Unit$(Chn)="strain" THEN
1893    Ymin=Def_ymin
1894    Ymax=Def_ymax
1895  END IF
1896  INPUT "ENTER NEW VALUE FOR YMIN OR CONT TO RESTORE DEFAULT ",Ymin
1897  INPUT "ENTER NEW VALUE FOR YMAX OR CONT TO RESTORE DEFAULT ",Ymax
1898  IF Unit$(Chn)="strain" THEN
1899    IF Ymin<>Def_ymin THEN Ymin=Ymin*1.E-6
1900    IF Ymax<>Def_ymax THEN Ymax=Ymax*1.E-6
1901  END IF
1902  GOSUB Plot_graph
1903  RETURN
1904  !
1905  !=========================================================
1906 New_xscale: !
1907  !=========================================================
1908  Xmin=Def_xmin
1909  Xmax=Def_xmax
1910  INPUT "ENTER NEW VALUE FOR XMIN OR CONT TO RESTORE DEFAULT ",Xmin
1911  INPUT "ENTER NEW VALUE FOR XMAX OR CONT TO RESTORE DEFAULT ",Xmax
1912  GOSUB Plot_graph
1913  RETURN
1914  !
1915 Set_scale: !
1916  PEN 0
1917  LORG 5
1918  CSIZE 5
1919  IF Position<>0 THEN MOVE T,Data(Position,Chn)*Calib(Chn)
1920  LABEL "+"
1921  PEN 1
1922  GOSUB Find_scale
1923  GOSUB Plot_frame
1924  GOSUB Plot_pts
1925  RETURN
1926 !
1927 ! *****************************************************************
1928 Default_scales:!
1929 ! *****************************************************************
1930  IF Unit$(1)="strain" THEN
1931    Def_ymin=-2.00E-4
1932    Def_ymax=2.00E-4
1933  ELSE
1934    Def_ymin=-5.0E+7
1935    Def_ymax=5.0E+7
1936  END IF
1937  Ymin=Def_ymin        ! DEFAULT SCALES
1938  Ymax=Def_ymax
1939  Xmin=Def_xmin
1940  Xmax=Def_xmax
1941  Old_ymin=Ymin
1942  Old_ymax=Ymax
1943  Old_xmin=Xmin
1944  Old_xmax=Xmax
1945  RETURN
1946    !
1947 Find_scale:  !
1948  !
```

```
1949  Xscale=ABS(Xmax-Xmin)
1950  Yscale=ABS(Ymax-Ymin)
1951  IF Xscale<=.01 THEN Xscale=1
1952  IF Yscale=0 THEN Yscale=1.E-9
1953  !
1954  Scale_mx=10^INT(LGT(Xscale))
1955  Scale_my=10^INT(LGT(Yscale))
1956  !
1957  ! DETERMINE INDICE FOR UNIT_SCALEs
1958  !
1959  Unit_iy=5-(LGT(Scale_my) DIV 3)
1960  Unit_ix=5-(LGT(Scale_mx) DIV 3)
1961  !
1962  IF LGT(Scale_my)<0 THEN
1963    IF LGT(Scale_my) MOD 3<>0 THEN
1964      Unit_iy=Unit_iy+1
1965    END IF
1966  END IF
1967  IF LGT(Scale_mx)<0 THEN
1968    IF LGT(Scale_mx) MOD 3<>0 THEN
1969      Unit_ix=Unit_ix+1
1970    END IF
1971  END IF
1972  !
1973  IF Unit_iy<1 THEN Unit_iy=1
1974  IF Unit_ix<1 THEN Unit_ix=1
1975  IF Unit_iy>11 THEN Unit_iy=11
1976  IF Unit_ix>11 THEN Unit_ix=11
1977  !
1978  DISP
1979  RETURN
1980  !
1981  ! ***********************************************************************
1982  ! PLOT DATA
1983  ! ***********************************************************************
1984  OFF KNOB
1985 Plot_frame:  !
1986  GOSUB Plot_frame1
1987  RETURN
1988  GOSUB X_grad
1989  GOSUB Y_grad
1990  DEG
1991  GINIT
1992  !
1993  Q$=""
1994  IF Pen_flg=1 THEN
1995    C_size=3.0
1996    PLOTTER IS 705,"HPGL"
1997    PRINTER IS 705
1998    Y_gdu=100*MAX(1,RATIO)
1999    X_gdu=100*MAX(1,1/RATIO)
2000    VIEWPORT .1*Y_gdu,.9*Y_gdu,.2*X_gdu,.8*X_gdu
2001  ELSE
2002    C_size=3.5
2003    PLOTTER IS CRT,"INTERNAL"
2004    PRINTER IS 1
2005    GRAPHICS ON
2006    X_gdu=100*MAX(1,RATIO)
2007    Y_gdu=100*MAX(1,1/RATIO)
2008    VIEWPORT .1*X_gdu,.9*X_gdu,.15*Y_gdu,.9*Y_gdu
```

```
2009  END IF
2010  !
2011  OUTPUT 2 USING "#,K";CHR$(255)&"K"           !CLEARS SCREEN FOR GRAPH
2012  !
2013  WINDOW Xmin,Xmax,Ymin,Ymax
2014  !
2015  CLIP OFF
2016  !
2017  IF Pen_flg=1 THEN
2018    PEN 1
2019  ELSE
2020    PEN 1
2021  END IF
2022  LORG 6
2023  CSIZE C_size
2024                                       !WRITE TITLE OF PLOT
2025  MOVE Xmin+Xscale*.5,1.05*Yscale+Ymin
2026 !LABEL USING "K";Title$
2027  !
2028                                       !WRITE ONLY TITLE OF PLOT
2029  MOVE Xmin+Xscale*.5,1.10*Yscale+Ymin
2030! LABEL USING "K";"1985 POLAR SEA IMPACT TESTS   (ARCTEC CANADA LTD.)"
2031  LABEL USING "K";Title$
2032    !
2033  LDIR 90                                   ! WRITE Y AXIS TITLE
2034  CSIZE C_size,.6
2035  MOVE Xmin-.13*Xscale,Ymin+Yscale*.5
2036  LABEL USING "K";Y_title$&"  "&Unit_scale$(Unit_iy)&" "&Y_units$
2037  !
2038  LORG 4                                    ! WRITE X AXIS TITLE
2039  CSIZE C_size
2040  LDIR 0
2041  MOVE Xmin+Xscale*.5,Ymin-.11*Yscale
2042  LABEL USING "K";X_title$&"  "&Unit_scale$(Unit_ix)&" "&X_units$
2043  !
2044 Label_fig: !
2045  IF Pen_flg=1 THEN                       ! WRITE FIGURE AND PROGRAM USED
2046    LORG 2
2047    MOVE Xmin,Ymin-.16*Yscale
2048    LABEL "PROGRAM USED: "&Program$
2049    LORG 5
2050    MOVE Xmin+Xscale*.5,Ymin-.24*Yscale
2051    INPUT "ENTER THE FIGURE NUMBER",Figure_no
2052    INPUT "ENTER THE TITLE OF FIGURE",Title$
2053    Title$="FIGURE "&VAL$(Figure_no)&": "&Title$
2054    LABEL USING "K";Title$
2055  END IF
2056  !
2057  !
2058  CLIP ON
2059  AXES X_tick,Y_tick,Xmin,Ymin,X_major,Y_major,3
2060  AXES X_tick,Y_tick,Xmax,Ymax,X_major,Y_major,3
2061  LINE TYPE 4
2062  IF Grid_flg=1 THEN GRID X_tick*X_major,Y_tick*Y_major,Xmin,Ymin,1,1
2063  !
2064  LINE TYPE 3
2065  IF SGN(Ymin*Ymax)<0 THEN
2066    MOVE Xmin,0                             ! DRAWS LINES AT  0,0
2067    PLOT Xmax,0,-1
2068  END IF
```

```
2069  !
2070  IF Ref_flg THEN
2071    LINE TYPE 1
2072    MOVE Refl,Ymin
2073    PLOT Refl,Ymax,-1
2074  END IF
2075  !
2076  CLIP OFF
2077  CSIZE C_size                                      ! NUMBERS X-AXIS
2078  LORG 6
2079  X_exp=10^(12-(3*(Unit_ix-1)))
2080  Linc=X_tick*X_major
2081  FOR Ir=Xmin TO Xmax STEP Linc
2082    IF ABS(Ir/X_exp)<1.E-8 AND ABS(Ir/X_exp)>-1.E-8 THEN Ir=0
2083    MOVE Ir,Ymin-.01*Yscale
2084    LABEL USING "K";VAL$(Ir/X_exp)
2085  NEXT Ir
2086   !
2087                                                    ! NUMBERS Y AXIS
2088  LORG 8
2089  CSIZE C_size,.6
2090  Linc=Y_tick*Y_major
2091  Y_exp=10^(12-(3*(Unit_iy-1)))
2092  FOR Ir=Ymin TO Ymax STEP Linc
2093    IF ABS(Ir/Y_exp)<1.E-8 AND ABS(Ir/Y_exp)>-1.E-8 THEN Ir=0
2094    MOVE Xmin-.01*Xscale,Ir
2095    LABEL USING "K";VAL$(Ir/Y_exp)
2096  NEXT Ir
2097  !
2098  !
2099  CLIP ON
2100  PEN 5
2101  RETURN
2102  !=====================================================
2103 Label_frames: !
2104  !======================================================
2105  CLIP OFF
2106  LORG 5
2107  !
2108  IF L_flg=0 THEN
2109    MOVE Loc_frame(10),0
2110    PLOT Loc_frame(10),.825*(Ymax-Ymin)+Ymin,-1
2111    MOVE Loc_frame(10),.85*(Ymax-Ymin)+Ymin
2112    LABEL USING "K";Fr$(10)
2113  END IF
2114  !
2115  MOVE Loc_frame(9),0
2116  PLOT Loc_frame(9),.87*(Ymax-Ymin)+Ymin,-1
2117  MOVE Loc_frame(9),.9*(Ymax-Ymin)+Ymin
2118  LABEL USING "K";Fr$(9)
2119  !
2120  IF L_flg=1 THEN
2121    MOVE Loc_frame(8),0
2122    PLOT Loc_frame(8),.87*(Ymax-Ymin)+Ymin,-1
2123    MOVE Loc_frame(8),.9*(Ymax-Ymin)+Ymin
2124    LABEL USING "K";Fr$(8)
2125  !
2126    MOVE Loc_frame(7),0
2127    PLOT Loc_frame(7),.87*(Ymax-Ymin)+Ymin,-1
2128    MOVE Loc_frame(7),.9*(Ymax-Ymin)+Ymin
```

```
2129    LABEL USING "K";Fr$(7)
2130  !
2131  END IF
2132  !
2133  MOVE Loc_frame(6),0
2134  PLOT Loc_frame(6),.825*(Ymax-Ymin)+Ymin,-1
2135  MOVE Loc_frame(6),.85*(Ymax-Ymin)+Ymin
2136  LABEL USING "K";Fr$(6)
2137  !
2138  MOVE Loc_frame(5),0
2139  PLOT Loc_frame(5),.87*(Ymax-Ymin)+Ymin,-1
2140  MOVE Loc_frame(5),.9*(Ymax-Ymin)+Ymin
2141  LABEL USING "K";Fr$(5)
2142  !
2143  MOVE Loc_frame(3),0
2144  PLOT Loc_frame(3),.87*(Ymax-Ymin)+Ymin,-1
2145  MOVE Loc_frame(3),.9*(Ymax-Ymin)+Ymin
2146  LABEL USING "K";Fr$(3)
2147  CLIP ON
2148  RETURN
2149    !
2150    !================================================
2151 Plot_pts:!
2152    !================================================
2153  OFF KNOB
2154  GRAPHICS ON
2155  LORG 5                                   ! PLOTS POINTS
2156  CSIZE 2.0
2157    !
2158  Time=Xmin
2159  T_step=1/Scan_rate
2160  MOVE Time,(Data(1,Chn)-Base_l(Chn))*Calib(Chn)
2161  FOR I=INT(Xmin*Scan_rate) TO INT(Xmax*Scan_rate)-1
2162    PLOT Time,(Data(I+1,Chn)-Base_l(Chn))*Calib(Chn),-1
2163    Time=Time+T_step
2164  NEXT I
2165  !
2166 !DISP "BASE LINE AVERAGE= ";Base_l(Chn)*Calib(Chn)
2167  Position=Xmin*Scan_rate
2168  Curs_flg=0
2169  ON KNOB .2,9 GOSUB Move_cursor
2170  IF Pen_flg=1 THEN
2171    PRINT "SP"
2172    MOVE Xmin,Ymax
2173  END IF
2174  !
2175  RETURN
2176  !
2177  ! ****************************************************************
2178  ! X_GRAD DETERMINES SCALE  FOR X AXIS
2179  ! ****************************************************************
2180 X_grad: !
2181  Xmin=Xmin/Scale_mx
2182  Xmax=Xmax/Scale_mx
2183  Xscale=ABS(Xmax-Xmin)
2184  IF Xscale<=1 THEN
2185    X_tick=.04
2186    X_major=5
2187  ELSE
2188    IF Xscale<=2 THEN
```

```
2189      X_tick=.1
2190      X_major=4
2191    ELSE
2192      IF Xscale<=5 THEN
2193        X_tick=.1
2194        X_major=5
2195      ELSE
2196        IF Xscale<=10 THEN
2197          X_tick=.2
2198          X_major=5
2199        END IF
2200      END IF
2201    END IF
2202  END IF
2203  ! Xmin=INT(Xmin/(X_tick*X_major))*Scale_mx*X_tick*X_major
2204  ! Xmax=(INT(Xmax/(X_tick*X_major))+1)*Scale_mx*X_tick*X_major
2205  Xmax=Xmax*Scale_mx
2206  Xmin=Xmin*Scale_mx
2207  Xscale=ABS(Xmax-Xmin)
2208  X_tick=X_tick*Scale_mx
2209  RETURN
2210   !
2211  ! ***************************************************************************
2212  ! Y_GRAD DETERMINES SCALE  FOR Y AXIS
2213  ! ***************************************************************************
2214 Y_grad: !
2215  Ymin=Ymin/Scale_my
2216  Ymax=Ymax/Scale_my
2217  Yscale=ABS(Ymax-Ymin)
2218  IF Yscale<=1 THEN
2219    Y_tick=.04
2220    Y_major=5
2221  ELSE
2222    IF Yscale<=2 THEN
2223      Y_tick=.1
2224      Y_major=4
2225    ELSE
2226      IF Yscale<=5 THEN
2227        Y_tick=.1
2228        Y_major=5
2229      ELSE
2230        IF Yscale<=10 THEN
2231          Y_tick=.2
2232          Y_major=5
2233        END IF
2234      END IF
2235    END IF
2236  END IF
2237  ! Ymin=INT(Ymin/(Y_tick*Y_major))*Scale_my*Y_tick*Y_major
2238 !  Ymax=(INT(Ymax/(Y_tick*Y_major))+1)*Scale_my*Y_tick*Y_major
2239  Ymin=Ymin*Scale_my
2240  Ymax=Ymax*Scale_my
2241  Yscale=ABS(Ymax-Ymin)
2242  Y_tick=Y_tick*Scale_my
2243  RETURN
2244   !
2245  ! ****************************************************************************
2246  ! MOVE CURSOR
2247  ! ****************************************************************************
2248 Move_cursor:  !
```

```
2249  PEN 0
2250  LORG 5
2251  CSIZE 5
2252  IF Curs_flg THEN
2253    MOVE T,(Data(Position,Chn)-Base_l(Chn))*Calib(Chn)
2254    LABEL "+"
2255  END IF
2256  Curs_flg=1
2257  Position_change=INT(KNOBX)
2258  Position=Position+Position_change
2259  IF Position<=Xmin*Scan_rate THEN Position=Xmax*Scan_rate
2260  IF Position>Xmax*Scan_rate THEN Position=Xmin*Scan_rate
2261  IF Position=0 THEN Position=1
2262  T=Position*T_step
2263  MOVE T,(Data(Position,Chn)-Base_l(Chn))*Calib(Chn)
2264  LABEL "+"
2265  PEN 1
2266  DISP I$;"           ";T;" Y ";(Data(Position,Chn)-Base_l(Chn))*Calib(Chn)
2267  RETURN
2268   !
2269  ! ***********************************************************************
2270  ! CHOOSE SECTION
2271  ! ***********************************************************************
2272 Choose_section: !
2273  RETURN
2274      !
2275  !
2276  ! ============================================================
2277  !   DUMP GRAPHICAL OUTPUT TO PRINTER
2278  ! ============================================================
2279 Dump_graphics:    !
2280  PEN 1
2281  IF Loc_flg THEN
2282    MOVE Loc_load(Rdg),.8*Ymin
2283    LORG 5
2284    LABEL USING "K";"LOC. LOAD"
2285  END IF
2286  Q$=""
2287 !INPUT "DO YOU WANT AN EXPANDED PLOT (Y,N)",Q$
2288  IF Q$="Y" THEN
2289    DUMP DEVICE IS 701,EXPANDED
2290  ELSE
2291    DUMP DEVICE IS 701
2292  END IF
2293  DUMP GRAPHICS
2294  PRINTER IS 701
2295  IF Bm_flg=1 OR Sh_flg=1 THEN
2296    PRINT "TIME= ";Rdg/Scan_rate;" Sec."
2297  END IF
2298  IF Sh_flg=1 THEN
2299    PRINT USING "10A,MDD.DDESZ,5X,10A,MDD.DDESZ";"POS AREA= ",Pos_area,"NEG
AREA= ",Neg_area
2300  END IF
2301  Q$=""
2302  RETURN
2303 Dump_spec: !
2304            PRINT CHR$(12)
2305  PRINT ""
2306  PRINT ""
2307  PRINT "PROGRAM USED: ";Program$
```

```
2308  PRINT "ANALYSIS DATE/TIME:    ";DATE$(TIMEDATE)&"/"&TIME$(TIMEDATE)
2309  PRINT "ACQUISTION DATE/TIME: ";Ac_date$&"/"&Ac_time$
2310    !
2311  PRINT ""
2312  IF Sh1<>0 THEN
2313    PRINT USING Max_table;"POS. SHEAR FORCE= ";Sh1;" MN   AT TIME= ";T_bf;"
sec.";" LOC.= ";Fr$(L_sh1-1)&" TO "&Fr$(L_sh1)
2314    ELSE
2315    PRINT USING Max_table;"POS. SHEAR FORCE= ";Sh1;" MN   AT TIME= ";T_bf;"
sec.";" LOC.= ";Fr$(L_sh1)
2316    END IF
2317    PRINT USING Max_table;"NEG. SHEAR FORCE= ";Sh2;" MN   AT TIME= ";T_bf;"
sec.";" LOC.= ";Fr$(L_sh2-1)&" TO "&Fr$(L_sh2)
2318    PRINT USING Max_table;"MAX. BEND.MOM.= ";Bm_min;" MNm  AT TIME= ";T_bm;"
 sec.";" LOC.= ";Fr$(L_bm)
2319    PRINT USING Max_table;"MAX. BEND.STRESS= ";Bm5_min*1.E-6;" Mpa. AT TIME=
 ";Tbm5;" sec.";" LOC.= ";Fr$(5)
2320    IF Speed>2 THEN PRINT USING Max_table;"MAXIMUM VELOCITY= ";Speed;" Knots
"
2321  PRINT ""
2322  DISP "PUSH CONT"
2323  PAUSE
2324  DISP ""
2325  PRINT ""
2326  PRINTER IS 1
2327  GOTO Main
2328   !
2329  ! ************************************************************************
2330  ! EXIT_GRAPHICS
2331  ! ************************************************************************
2332 Exit_graphics:    !
2333  GRAPHICS OFF
2334  P_flg=-P_flg
2335  PLOTTER IS CRT,"INTERNAL"
2336  PRINTER IS 1
2337  LORG 5
2338  CSIZE 5
2339  !IF Position<>0 THEN MOVE T,Data(Position,Chn)
2340  !LABEL "+"
2341  OFF KNOB
2342  DISP ""
2343  OFF KEY
2344  PRINTER IS 1
2345  PLOTTER IS CRT,"INTERNAL"
2346  GOTO Main
2347  !
2348  !
2349 Dummy_data:        !
2350  FOR I=1 TO 26
2351  Calib(I)=2.487E-6
2352   ! Unit$(I)="Pa."
2353  ! Gf(I)=2.01
2354  ! Excit(I)=10
2355  ! Brge(I)=2
2356  ! Gf(I)=Tgf(I)
2357   !Excit(I)=Texcit(I)
2358   !Brge(I)=Tbrge(I)
2359   !Long(I)=Long(I)
2360  ! Vert(I)=Vert(I)
2361  ! Unit$(I)=Tunit$(I)
```

```
2362  NEXT I
2363  RETURN
2364  ! ****************************************************************
2365  !
2366 Configure:!
2367  ! ********************************************************
2368  ON KEY 0 LABEL "SAVE CONFIG",1 GOSUB Save_config
2369  ON KEY 1 LABEL "FIRST PAGE",1 GOSUB First_page
2370  ON KEY 2 LABEL "CHANGE",1 GOSUB Change_list
2371  ON KEY 3 LABEL "DELETE",1 GOSUB Delete
2372  ON KEY 4 LABEL "NEXT TABLE ",1 GOSUB Table_1_2
2373  ON KEY 5 LABEL "READ CONFIG",1 GOSUB Read_config
2374  ON KEY 6 LABEL "NEXT PAGE ",1 GOSUB Next_page
2375  ON KEY 7 LABEL "NEXT SENSOR",1 GOSUB Next_sensor
2376  ON KEY 8 LABEL "INSERT",1 GOSUB Insert_chan
2377  ON KEY 9 LABEL "RETURN",1 GOTO End_config
2378 Wait_config:GOTO Configure
2379 End_config: !
2380  PRINT CHR$(12)
2381  GOTO Main
2382  !===============================================================
2383 Table_1_2: !
2384  !===============================================================
2385  Table_flg=-Table_flg
2386  GOSUB Print_table
2387  RETURN
2388  !
2389  !
2390 Delete:!
2391  ! ********************************************************
2392  ON KEY 5 LABEL "DELETE PAGE",5 GOSUB Del_page
2393  ON KEY 6 LABEL "DELETE SECTION",5 GOSUB Del_sec
2394  ON KEY 7 LABEL "DELETE CHAN ",5 GOSUB Delete_1chan
2395  ON KEY 8 LABEL "NEXT SENSOR",5 GOSUB Next_sensor
2396  ON KEY 9 LABEL "RETURN ",5 GOTO Return_del
2397  ON KEY 0 LABEL "PRINT DATA",5 GOSUB Print_config
2398  ON KEY 1 LABEL "",5 GOTO Delete
2399  ON KEY 2 LABEL "",5 GOTO Delete
2400  ON KEY 3 LABEL "",5 GOTO Delete
2401  ON KEY 4 LABEL "",5 GOTO Delete
2402  GOTO Delete
2403 Return_del:!
2404  DISP ""
2405  RETURN
2406  !
2407  !********************************************************
2408 Delete_1chan: !
2409  !********************************************************
2410  N_del=1
2411  GOSUB Delete_chan
2412  RETURN
2413  !
2414  !**********************************************************
2415 Del_page: !
2416  !********************************************************
2417  N_del=Chn2-Chn1+1
2418  Chn=Chn1
2419  GOSUB Delete_chan
2420  RETURN
2421  !**********************************************************
```

```
2422 Del_sec:!
2423  INPUT "ENTER THE FIRST CHANNEL No. OF SECTION TO DELETE",Del_1
2424  INPUT "ENTER THE LAST CHANNEL No. OF SECTION TO DELETE ",Del_2
2425  N_del=Del_2-Del_1+1
2426  Chn=Del_1
2427  GOSUB Delete_chan
2428  RETURN
2429  !*********************************************************
2430  !************************************************************
2431 First_page: !
2432  !************************************************************
2433  Chn1=1
2434  Chn2=Chn1+Chn_p
2435  GOSUB Print_table
2436  RETURN
2437  !************************************************************
2438 Next_page: !
2439  !************************************************************
2440  Chn1=Chn1+Chn_p+1
2441  Chn2=Chn1+Chn_p
2442  IF Chn2>Nchns AND Chn1<=Nchns THEN Chn2=Nchns
2443  IF Chn1>Nchns THEN
2444  Chn1=1
2445  Chn2=Chn1+Chn_p
2446  END IF
2447  GOSUB Print_table
2448  RETURN
2449   !
2450  !****************************************************************
2451 Print_table: !
2452  !******************************************************************
2453  IF Chn1>Nchns THEN
2454  Chn1=Nchns-Chn_p
2455  Chn2=Chn1+Chn_p
2456  END IF
2457  IF Chn2>Nchns THEN Chn2=Nchns
2458  IF Chn2-Chn1>Chn_p THEN Chn2=Chn1+Chn_p
2459  IF Chn1<1 THEN
2460  PRINT CHR$(12)
2461  DISP "NO MORE CHANNELS "
2462  BEEP
2463  RETURN
2464  END IF
2465  !
2466  PRINT CHR$(12)
2467  PRINT ""
2468  GOSUB Print_titles
2469  PRINT ""
2470  Row=Row_o
2471  FOR Chn=Chn1 TO Chn2
2472  PRINT TABXY(1,Row)
2473  GOSUB Print_values
2474  Row=Row+1
2475  NEXT Chn
2476  Row=Row_o
2477  Chn=Chn1
2478  PRINT CHR$(129)
2479  PRINT TABXY(1,Row)
2480  GOSUB Print_values
2481  PRINT CHR$(128)
```

```
2482  RETURN
2483  !
2484 |**************************************************************
2485 Next_sensor: !
2486 |**************************************************************
2487  Chn=Row-Row_o+Chn1
2488  PRINT TABXY(1,Row-1)
2489  PRINT CHR$(128)
2490  GOSUB Print_values
2491  Row=Row+1
2492  IF Row=Chn2-Chn1+1+Row_o THEN Row=Row_o
2493  IF Chn>Nchns THEN Row=Row_o
2494  Chn=Row-Row_o+Chn1
2495  PRINT CHR$(129)
2496  PRINT TABXY(1,Row)
2497  GOSUB Print_values
2498  PRINT CHR$(128)
2499  RETURN
2500  !
2501  |==============================================================
2502 Change_list: !
2503  |==============================================================
2504  IF Table_flg=1 THEN
2505  INPUT "ENTER CHAN. ID. (10 CHARACTERS)",Id$(Chn)
2506  INPUT "ENTER CALIB. (MDDD.D)",Calib(Chn)
2507    !INPUT "ENTER OFF SET (MDDD.D)",Offs(Chn)
2508  INPUT "ENTER GAUGE FACTOR  (D.DD)",Gf(Chn)
2509  INPUT "ENTER EXCITATION ",Excit(Chn)
2510  INPUT "ENTER BRIDGE CONFIGURATION (1,.75,.5,.25)",Brge(Chn)
2511    !INPUT "ENTER ALARM LIMIT",Alarm(Chn)
2512  INPUT "ENTER UNITS",Unit$(Chn)
2513  ELSE
2514  INPUT "ENTER CHAN. ID.",Id$(Chn)
2515  INPUT "ENTER LONGITUDINAL LOCATION",Long(Chn)
2516 !  INPUT "ENTER TRANSVERSE LOCATION",Trans(Chn)
2517  INPUT "ENTER VERTICAL LOCATION",Vert(Chn)
2518   !INPUT "ENTER FRAME LOCATION",Fr(Chn)
2519  END IF
2520  PRINT CHR$(129)
2521  PRINT TABXY(1,Row)
2522  GOSUB Print_values
2523  PRINT CHR$(128)
2524  RETURN
2525  |============================================================
2526 Delete_chan: !
2527  |==============================================================
2528  DISP "DELETING CHANNEL PLEASE WAIT"
2529  Nchns=Nchns-N_del
2530  FOR I=Chn TO Nchns
2531  Id$(I)=Id$(I+N_del)
2532  Calib(I)=Calib(I+N_del)
2533  ! Offs(I)=Offs(I+N_del)
2534  Gf(I)=Gf(I+N_del)
2535  Excit(I)=Excit(I+N_del)
2536  Brge(I)=Brge(I+N_del)
2537    !Alarm(I)=Alarm(I+N_del)
2538  Unit$(I)=Unit$(I+N_del)
2539  Long(I)=Long(I+N_del)
2540  Trans(I)=Trans(I+N_del)
2541  Vert(I)=Vert(I+N_del)
```

```
2542  Fr(I)=Fr(I+N_del)
2543  NEXT I
2544  DISP ""
2545  GOSUB Print_table
2546  RETURN
2547  !==============================================================
2548 Insert_chan: !
2549  !==============================================================
2550  Nchns=Nchns+1
2551  IF Nchns>256 THEN
2552  BEEP
2553  DISP "NO MORE CHANNELS AVAILABLE"
2554  WAIT 2
2555  DISP ""
2556  Nchns=256
2557  RETURN
2558  END IF
2559  FOR I=Nchns TO Chn+1 STEP -1
2560  Id$(I)=Id$(I-1)
2561  Calib(I)=Calib(I-1)
2562 !  Offs(I)=Offs(I-1)
2563  Gf(I)=Gf(I-1)
2564  Excit(I)=Excit(I-1)
2565  Brge(I)=Brge(I-1)
2566  Unit$(I)=Unit$(I-1)
2567  Long(I)=Long(I-1)
2568  Trans(I)=Trans(I-1)
2569  Vert(I)=Vert(I-1)
2570  Fr(I)=Fr(I-1)
2571  NEXT I
2572  INPUT "ENTER CHAN. ID. (10 CHARACTERS)",Id$(Chn)
2573  INPUT "ENTER CALIB. (MDDD.D)",Calib(Chn)
2574 !INPUT "ENTER OFF SET (MDDD.D)",Offs(Chn)
2575  INPUT "ENTER GAUGE FACTOR  (D.DD)",Gf(Chn)
2576  INPUT "ENTER EXCITATION ",Excit(Chn)
2577  INPUT "ENTER BRIDGE CONFIGURATION (1,.75,.5,.25)",Brge(Chn)
2578  !INPUT "ENTER ALARM LIMIT",Alarm(Chn)
2579  INPUT "ENTER UNITS",Unit$(Chn)
2580  INPUT "ENTER LONGITUDINAL LOCATION",Long(Chn)
2581  INPUT "ENTER TRANSVERSE LOCATION",Trans(Chn)
2582  INPUT "ENTER VERTICAL LOCATION",Vert(Chn)
2583  INPUT "ENTER FRAME LOCATION",Fr(Chn)
2584  Chn2=Chn2+1
2585  GOSUB Print_table
2586  GOSUB Next_chan
2587  RETURN
2588  !
2589  !*********************************************
2590 Save_config:!
2591  !*********************************************
2592  INPUT "ENTER THE FILE NAME (MAXIMUNM OF 10 CHARACTERS",File$
2593  DISP "CREATING FILE AND STORING ON DISC"
2594  File$=File$
2595  Bytes=50*8*9+2+50*10+50*6+4*50+4*50
2596  Records=INT(Bytes/256)+1
2597  ON ERROR GOTO Purge_config
2598 Create_config:CREATE BDAT File$,Records,256
2599  ASSIGN @Path TO File$
2600  OUTPUT @Path;Nchns,Calib(*),Offs(*),Long(*),Trans(*),Vert(*),Fr(*),Id$(*),
Unit$(*),Gf(*),Excit(*),Brge(*)
```

```
2601  ASSIGN @Path TO *
2602  DISP ""
2603  RETURN
2604    !============================================================
2605 Purge_config:   !
2606    !==========================================================
2607  OFF ERROR
2608  INPUT "FILE ALREADY ON DISC ENTER P TO PURGE FILE",Purge$
2609  IF Purge$="P" THEN
2610  ASSIGN @Path TO *
2611  PURGE File$
2612  GOTO Create_config
2613  ELSE
2614  GOTO Sensor_sub
2615  END IF
2616  !*************************************************
2617 Read_config:!
2618  !*************************************************
2619  INPUT "ENTER THE FILE NAME (MAXIMUNM OF 10 CHARACTERS",File$
2620  Config$=File$[1,8]
2621  DISP "READING CONFIGURATION FILE:";File$
2622  File$=File$&D0$
2623  ASSIGN @Path TO File$
2624  ENTER @Path:Nchns,Calib(*),Offs(*),Long(*),Trans(*),Vert(*),Fr(*),Id$(*),U
nit$(*),Gf(*),Excit(*),Brge(*)
2625  ASSIGN @Path TO *
2626  DISP ""
2627  RETURN
2628  !************************************************************
2629 Print_config:!
2630  !************************************************************
2631  PRINTER IS 701
2632  INPUT "ENTER THE TABLE NO.",Table_no$
2633  PRINT USING "37X,9A";"TABLE "&Table_no$
2634  FOR Tables=1 TO 1
2635  PRINT ""
2636  PRINT "                              POLAR SEA IMPACT TESTS FALL 1985"
2637  PRINT ""
2638  PRINT "CONFIGURATION FILE: ";Config$
2639    !PRINT "DATE   ";DATE$(TIMEDATE)
2640    !PRINT "TIME   ";TIME$(TIMEDATE)
2641  IF Table_flg=1 THEN
2642    IF Config$="ENGUNIT1" THEN
2643      PRINT "FOR RAM 1 AND RAM 2"
2644    ELSE
2645      PRINT "FOR RAM 3 TO RAM 40"
2646    END IF
2647  ELSE
2648    PRINT "FOR RAM 1 TO RAM 40"
2649  END IF
2650  PRINT ""
2651  Chn_p=48
2652  Chn1=1
2653  Chn2=48
2654  Npages=INT(Nchns/Chn_p)
2655  IF Nchns MOD Chn_p>0 THEN Npages=Npages+1
2656  FOR Page=1 TO Npages
2657    GOSUB Print_titles
2658    PRINT ""
2659    FOR Chn=Chn1 TO Chn2
```

```
2660      GOSUB Print_values
2661    NEXT Chn
2662    PRINT CHR$(12)
2663    Chn1=Chn1+Chn_p+1
2664    Chn2=Chn1+Chn_p
2665    IF Chn2>Nchns THEN Chn2=Nchns
2666  NEXT Page
2667  Table_flg=-Table_flg
2668  NEXT Tables
2669  PRINTER IS 1
2670  RETURN
2671  !==========================================================
2672 Print_titles: !
2673  !===========================================================
2674  IF Table_flg=1 THEN
2675  PRINT "                      SENSOR SPECIFICATIONS"
2676  PRINT USING Title_1;"CHAN#","CHAN ID"," CALIB ","G. F. ","EXIT. ","BRIDGE"
,"UNITS"
2677  ELSE
2678  PRINT "                      SENSOR LOCATIONS"
2679  PRINT USING Title_2;"CHAN#","CHAN ID"," LONG(m.)"," VERT(m.)"
2680  END IF
2681  !
2682  RETURN
2683  !
2684  !===========================================================
2685 Print_values: !
2686  !===========================================================
2687  IF Table_flg=1 THEN
2688  PRINT USING Values1;Chn,Id$(Chn),Calib(Chn),Gf(Chn),Excit(Chn),Brge(Chn),U
nit$(Chn)
2689  ELSE
2690  PRINT USING Values2;Chn,Id$(Chn),Long(Chn),Vert(Chn)
2691  END IF
2692  RETURN
2693    !
2694    !================================================================
2695 Cubic_spline:   !
2696!  PROGRAM "CUBIC SPLINE CURVE FITTING" BY D.N. BRUCE COWPER 85/08/30
2697    !================================================================
2698!
2699  MAT Aa= (0)
2700  MAT Kk= (0)
2701  MAT Dd= (0)
2702  MAT Deltax= (0)
2703  MAT Deltay= (0)
2704  MAT Ddd= (0)
2705  REDIM Aa(Npts+1,Npts+1)
2706  REDIM Kk(Npts+1,1)
2707  REDIM Dd(Npts+1,1)
2708  !REDIM Xx(Npts),Yy(Npts)
2709  REDIM Deltax(Npts-1)
2710  REDIM Deltay(Npts-1)
2711  REDIM Ddd(Npts-1)
2712!
2713  FOR I=2 TO Npts
2714  Deltax(I-1)=Xx(I)-Xx(I-1)
2715  Deltay(I-1)=Yy(I)-Yy(I-1)
2716  Ddd(I-1)=Deltay(I-1)/Deltax(I-1)
2717  NEXT I
```

```
2718!   MATRIX A
2719  Aa(1,1)=2
2720  Aa(1,2)=1
2721  Aa(Npts,Npts-1)=1
2722  Aa(Npts,Npts)=2
2723!
2724  FOR I=2 TO Npts-1
2725  Aa(I,I-1)=Deltax(I)
2726  Aa(I,I)=2*(Deltax(I-1)+Deltax(I))
2727  Aa(I,I+1)=Deltax(I-1)
2728  NEXT I
2729  !   MATRIX D
2730  Dd(1,1)=Ddd(1)
2731  Dd(Npts,1)=Ddd(Npts-1)
2732  FOR I=2 TO Npts-1
2733  Dd(I,1)=Ddd(I-1)*Deltax(I)+Ddd(I)*Deltax(I-1)
2734  NEXT I
2735  ! FIND MATRIX K
2736  MAT Aa= INV(Aa)
2737  MAT Kk= Aa*Dd
2738  MAT Kk= Kk*(3)
2739  !
2740  I=0
2741  MAT Xp= (0)
2742  MAT Yp= (0)
2743  Yp(1)=Yy(1)
2744  Xp(1)=Xx(1)
2745  FOR N=Xx(1) TO Xx(Npts) STEP ABS(Xx(Npts)-Xx(1))/140
2746  I=I+1
2747  Xp(I)=N
2748  FOR X_cnt=1 TO Npts-1
2749    IF N<=Xx(X_cnt+1) THEN Calc_y
2750  NEXT X_cnt
2751 Calc_y:M=X_cnt
2752  T=(N-Xx(M))/Deltax(M)
2753  Tbar=1-T
2754  Yp(I)=T*Yy(M+1)+Tbar*Yy(M)+Deltax(M)*((Kk(M,1)-Ddd(M))*T*Tbar^2-(Kk(M+1,1)
-Ddd(M))*T^2*Tbar)
2755  NEXT N
2756  Cub_pts=I
2757  !
2758  LINE TYPE 5
2759  PEN 1
2760  MOVE Xp(1),Yp(1)
2761  FOR K=2 TO Cub_pts
2762  PLOT Xp(K),Yp(K),-1
2763  NEXT K
2764  !
2765 Label_curves: !
2766  MOVE .05*Xmax,.75*Ymin
2767  PLOT .15*Xmax,.75*Ymin,-1
2768  LINE TYPE 1
2769  CSIZE C_size*.8
2770  LORG 2
2771  LABEL " CUBIC SPLINE FIT"
2772  MOVE .05*Xmax,.65*Ymin
2773  CSIZE C_size*2
2774  LABEL "+"
2775  CSIZE C_size*.8
2776  MOVE .15*Xmax,.65*Ymin
```

```
2777  LABEL " MEASURED POINTS"
2778  !===============
2779 Calc_area: !
2780  !================
2781  DISP "CALCULATING AREA"
2782  Pos_area=0
2783  Neg_area=0
2784  FOR J=1 TO Cub_pts-1
2785  IF Shcalc=1 THEN
2786    Yp(J)=Ysh(J)
2787    Yp(J+1)=Ysh(J+1)
2788    Xp(J+1)=Xsh(J+1)
2789    Xp(J)=Xsh(J)
2790  END IF
2791  IF Yp(J+1)>0 THEN
2792    Pos_area=Pos_area+(Xp(J+1)-Xp(J))*.5*(Yp(J+1)+Yp(J))
2793  ELSE
2794    Neg_area=Neg_area+(Xp(J+1)-Xp(J))*.5*(Yp(J+1)+Yp(J))
2795  END IF
2796  NEXT J
2797  Pos_area=Pos_area*1.E-6
2798  Neg_area=Neg_area*1.E-6
2799  DISP USING "10A,MDD.DDESZ,5X,10A,MDD.DDESZ,3X,10A";"POS AREA= ",Pos_area,"
NEG AREA= ",Neg_area;"PUSH CONT"
2800 !PAUSE
2801  !================
2802 C_sh_curve: !
2803  !================
2804  IF Bm_flg THEN
2805 !  DISP "CALCULATING SHEAR CURVE"
2806  Sh_pts=0
2807  FOR I=2 TO Cub_pts
2808    Sh_pts=Sh_pts+1
2809    Xsh(I)=Xp(I-1)+.5*(Xp(I)-Xp(I-1))
2810    Ysh(I)=-(Yp(I)-Yp(I-1))/(Xp(I)-Xp(I-1))
2811  NEXT I
2812  END IF
2813  Shcalc=0
2814  !
2815  !
2816  RETURN
2817  !=================
2818 P_sh_curve: !
2819  !================
2820  PEN 1
2821  Shcalc=1
2822  GOSUB Calc_area
2823  LINE TYPE 5
2824  MOVE Xsh(1),Ysh(1)
2825  FOR I=2 TO Sh_pts
2826  PLOT Xsh(I),Ysh(I),-1
2827  NEXT I
2828  MOVE .05*Xmax,.75*Ymin
2829  PLOT .15*Xmax,.75*Ymin,-1
2830  LINE TYPE 1
2831  CSIZE C_size*.8
2832  LORG 2
2833  LABEL " FROM CUBIC SPLINE"
2834  MOVE .05*Xmax,.65*Ymin
2835  CSIZE C_size*2
```

```
2836  LABEL "+"
2837  CSIZE C_size*.8
2838  MOVE .15*Xmax,.65*Ymin
2839  LABEL " FROM MEASURED POINTS"
2840  !
2841  GOTO P_bsh
2842  !================================================================
2843 Label_figure: !
2844  !================================================================
2845  !
2846  INPUT "ENTER THE FIGURE LABEL",Title$
2847  !
2848  PEN 2
2849  PLOTTER IS 705,"HPGL"
2850  X_gdu=10*100*RATIO/20
2851  Y_gdu=8*100/8.5
2852  VIEWPORT .1*X_gdu,.9*X_gdu,.15*Y_gdu,.9*Y_gdu
2853  WINDOW 0,100,0,100
2854  CSIZE 2
2855  MOVE 50,-20
2856  LORG 4
2857  CLIP OFF
2858  LABEL USING "K":Title$
2859  CLIP ON
2860  PEN 0
2861  PLOTTER IS CRT,"INTERNAL"
2862  PEN 1
2863  RETURN
2864  !
2865  ! *********************************************************************
2866  ! PLOT FRAME
2867 Plot_frame1:!
2868  ! *********************************************************************
2869            !
2870  DEG
2871  GINIT
2872  GRAPHICS ON
2873  PLOTTER IS CRT,"INTERNAL"
2874  GOSUB X_grad                                 ! FIND SCALE FOR X AXIS
2875  GOSUB Y_grad                                 ! FIND SCALE FOR Y AXIS
2876  !
2877  IF Pen_flg<>1 THEN
2878  OUTPUT 2 USING "#,K":CHR$(255)&"K"           !CLEARS SCREEN FOR GRAPH
2879  X_gdu=100*MAX(1,RATIO)
2880  Y_gdu=100*MAX(1,1/RATIO)
2881  C_size=3.5
2882  ELSE
2883  PLOTTER IS 705,"HPGL"
2884  X_gdu=10*100*RATIO/20
2885  Y_gdu=8*100/8.5
2886  C_size=2
2887  PEN 1
2888  END IF
2889  !
2890  VIEWPORT .1*X_gdu,.9*X_gdu,.15*Y_gdu,.9*Y_gdu
2891  !
2892    !
2893           !
2894  FOR I=1 TO 1
2895  WINDOW Xmin,Xmax,Ymin,Ymax
```

```
2896    !
2897  AXES X_tick,Y_tick,Xmin,Ymin,X_major,Y_major,3
2898  AXES X_tick,Y_tick,Xmin,Ymax,X_major,Y_major,3
2899  AXES 1000*X_tick,Y_tick,Xmax,Ymax,X_major,Y_major,3
2900  IF Pen_flg<>1 THEN
2901    LINE TYPE 3
2902    GRID X_tick*X_major,Y_tick*Y_major,Xmin,Ymin,1,1
2903  END IF
2904  !
2905  NEXT I
2906  LINE TYPE 1
2907  !
2908  !
2909  !
2910  !====================================================
2911 Title_label: !
2912  !====================================================
2913  !
2914  PEN 1
2915  !
2916  LORG 6
2917  CLIP OFF
2918                                                  !WRITE TITLE OF PLOT
2919  CSIZE C_size
2920  MOVE Xmin+(Xmax-Xmin)*.5,Ymin+1.1*(Ymax-Ymin)
2921 !LABEL USING "K";Title$
2922  !
2923  CSIZE C_size*1.1                                ! WRITE ONLY TITLE
2924  MOVE Xmin+(Xmax-Xmin)*.5,Ymin+1.05*(Ymax-Ymin)
2925 !LABEL USING "K";"1985 POLAR SEA IMPACT TESTS   (ARCTEC CANADA LTD.)"
2926  LABEL USING "K";Title$
2927  !
2928  !
2929  !=================================================
2930 Axis_title: !
2931  !=================================================
2932  !
2933  LDIR 90                                        ! WRITE Y AXIS TITLE
2934  CSIZE C_size,.6
2935  IF Polar_flg=0 THEN
2936  MOVE Xmin-.12*(Xmax-Xmin),(Ymin+Ymax)*.5
2937  ELSE
2938  MOVE Xmin-.12*(Xmax-Xmin),(Ymin+Ymax)*.5
2939  END IF
2940  LABEL USING "K";Y_title$&"  "&"("&Unit_scale$(Unit_iy)&Y_unit$&")"
2941  !
2942  LORG 4                                         ! WRITE X AXIS TITLE
2943  CSIZE C_size
2944  LDIR 0
2945  MOVE Xmin+(Xmax-Xmin)*.5,Ymin-.11*(Ymax-Ymin)
2946  LABEL USING "K";X_title$&"  "&"("&Unit_scale$(Unit_ix)&X_unit$&")"
2947  !
2948  !
2949  !
2950  !==============================================================
2951 Label_axis: !
2952  !==============================================================
2953  !
2954  LINE TYPE 3
2955  IF SGN(Ymin*Ymax)<0 THEN
```

```
2956  MOVE Xmin,0                                ! DRAWS LINES AT  0,0
2957  DRAW Xmax,0
2958  MOVE 0,Ymin
2959  DRAW 0,Ymax
2960  END IF
2961  !
2962  LINE TYPE 1
2963  CLIP OFF
2964  !
2965  CSIZE C_size                          ! NUMBERS X-AXIS
2966  LORG 6
2967  X_exp=10^(12-(3*(Unit_ix-1)))
2968  Linc=X_tick*X_major
2969  FOR Ir=Xmin TO Xmax STEP Linc
2970  IF ABS(Ir/X_exp)<1.E-8 AND ABS(Ir/X_exp)>-1.E-8 THEN Ir=0
2971  MOVE Ir,Ymin-.02*Yscale
2972  LABEL USING "K";VAL$(Ir/X_exp)
2973  NEXT Ir
2974   !
2975                                             ! NUMBERS Y AXIS
2976  LORG 8
2977  CSIZE C_size,.6
2978  Linc=Y_tick*Y_major
2979  Y_exp=10^(12-(3*(Unit_iy-1)))
2980  FOR Ir=Ymin TO Ymax STEP Linc
2981  IF ABS(Ir/Y_exp)<1.E-8 AND ABS(Ir/Y_exp)>-1.E-8 THEN Ir=0
2982  MOVE Xmin-.01*Xscale,Ir
2983  LABEL USING "K";VAL$(Ir/Y_exp)
2984  NEXT Ir
2985  !
2986  CLIP ON
2987  RETURN
2988  !
2989  END
```

APPENDIX E

SUMMARY OF REPORT FROM ABS ON FINITE ELEMENT AND ANALYTICAL MODELING

The strain gauge measurement records acquired during the USCGC POLAR SEA fall 1985 deployment represent a unique data base for predicting ice induced forces due to ramming icebreaking. The American Bureau of Shipping (ABS) analyzed this data with an overall objective aimed at the development of an analytical model capable of describing the ship/ice impact interaction. Two models were developed in the study done by ABS: one was an analytical model, and the other was a finite element model. The recorded data of the ramming forces was analyzed and compared with the forces predicted by the analytical model. The finite element model was executed for various load cases including those loads calculated from the full scale bending stress measurements. The stress predicted from the model was compared to the measured stress for each corresponding load case. This appendix summarizes a report produced by ABS on these models [20].

Ramming Force Analysis with an Analytical Model

The Ocean Engineering Division of ABS worked on the analytical model of ship/ice interaction. The recorded data of the ramming forces, their durations and time histories, ramming velocity, and the locations of the ramming forces are analyzed and compared with those predicted by the analytical model for the actual testing conditions. The model describes the ice impact loads on ships as functions of ship and ice masses, their dimensional and inertial characteristics, contact zone shapes, the mechanical properties of ice, and the relative impact velocity.

The POLAR SEA has a bow with flare angles at the stem exceeding 60° and a stem inclination angle that varies with an angle of less than 20° at the design water line. This shape is treated as an intermediate shape between a perfect wedge and a spoon-shaped bow. The shapes of the ice ridges vary greatly and individual ridges can differ significantly from each other,; however an estimate of the shape of the ridges impacted were made using the information regarding the keel depth and sail height. The dynamic crushing strength of the ice was approximated to be the average strength of first and second-year ice of the Northern Beaufort Sea.

Eleven of the bow force time histories derived from the full scale measurements were compared to force time histories predicted from the model. The time domain theoretical curve derived from the analytical model agreed well with the full scale test results, and fit almost perfectly with several rams 2, 3, 14, 15, 17, 34 and 39. The predicted shape and the time at which the maximum bow force occurred compared well with each other. The best agreement between the predicted an vertical forces was for the rams with a single distinct peak force. These are rams 2, 14, and 15 for which the ratio of predicted-to-recorded vertical forces is, respectively, 0.89, 1.01 and 1.39. The ram with the highest impact force, ram 39, resulted in a ratio of 0.81.

The uncertainty of the shape of the ridge at the point of impact and the velocity of impact for rams with several force peaks, are sources of the apparent disagreements between predicted and recorded forces. The estimate of the ice properties is also a source of error as the properties can vary considerably through one ridge during a ramming event.

To refine the model for accurate force predictions more ice property data is required along with accurate measurements of the ship motion during the impact process. The experimental studies which can be most valuable for refinement of the analytical model may include: ramming tests in very thick level ice, ramming tests at various size bergy-bits of glacial ice, and in-situ ball-dropping or pendulum tests, to specifically measure ice properties.

Hull Structural Response - Finite Element Analysis

The dynamic structural analysis was performed using a three-dimensional finite element model representing the entire vessel including the deckhouse and other superstructures. At the forward end of the vessel where the ice impact loads occurred, a fine mesh model was used to connect through a transition segment to a coarser mesh representation of the remainder of the vessel. This was to ensure that the structural response in the areas of interest could be determined accurately.

A free vibration analysis was first carried out to determine the natural frequencies and mode shapes representing the coupled hull girder and deckhouse vibration. Then, a forced vibration was performed to obtain the transient response of the vessel to time varying impact loads. The ice impact loads used in the analysis were obtained from the measured data corresponding to Ram 14 and Ram 39. Case studies were also included for ice impact loads with predefined shapes of time functions, including the ABS analytical model described previously.

The structural analysis was performed for the vessel ramming in ice at a head-on condition. This results in a condition of symmetry about the centreline plane of the vessel, allowing the analysis to be performed on a model representing only one half of the ship, in this case the port side. The static characteristics of the vessel afloat were determined by using the ABS/SHIPMOM program for the calculation of the buoyancy springs. The output from this program was then used to determine the dynamic characteristics of the vessel for the calculation of added mass with the aid of the ABS/ADMASS program, which is based on the linearized ideal fluid theory and the use of the boundary integral method. The effects of internal and hydrodynamic damping were introduced in the pertinent calculations of structural response. The free vibration characteristics and the dynamic response of the mathematical model to the ice impact loads were calculated by means of the SAP-V program.

The finite element model has 35 transverse frames. A summary of the characteristics of the model is shown below:

Number of nodes	1383
Number of degrees of freedom	3651
Number of elements:	
Truss elements	960
Beam elements	805
Plate elements	1954
Total Elements	**3719**

The added mass in the vertical direction was found to be 98% of the total displacement of the loaded vessel. No transverse or longitudinal components were included since lateral vibrations were not considered in the analysis and the longitudinal added mass is considered negligible in this case. In this analysis, a damping value equal to 5% of critical damping was used. This value was divided into two factors proportional to the mass and stiffness matrices (Rayleigh damping) for use in the SAP-V program.

The free vibration analysis determined the natural frequencies and mode shapes corresponding to the lowest 10 modes. The first three modes represent the rigid body motions, and the remaining modes represent elastic deformations. The 2-node to 5-node vibration corresponded to the vertical bending vibrations. The higher modes indicate hull girder vibration coupled with deckhouse and local vibrations. The 2-node bending frequency (4th mode) was calculated to be 3.06 Hz, which corresponded to the dominant measured bending frequency.

Ice impact loads applied to the structure were represented by time varying loads. Nine load cases were selected for the dynamic analysis: The first three cases were a triangular shape, concave shape, and a convex shape all at a constant location between cant frames 21 and 25. The fourth load case was the ABS theoretical bow force curve applied at the same location. The fifth to seventh case were the measured bow force time history of Ram 39 at two constant locations and one moving load from cant frame 21 to cant frame 45. The last two load cases were the measured bow force time history of Ram 14 applied at two separate load locations.

The results from the first three load cases indicated that the peak stress values obtained for the three load cases were about the same in magnitude, although the instant at which the peak stress occurred did vary slightly. It is noted that the variation of the calculated peak stress values was not significant for different shapes of forcing functions, if the loads are applied to the same location. However, the variation of peak stresses were significantly different when impacts were applied to different locations. The ratio of the calculated peak stress to the measured stress when a moving load corresponding to Ram 39 was applied was 1.09. This was the best correlation between the finite element model results and the measured results, and it was the only load case where the applied load was moving down the bow. The maximum peak stresses obtained from the model did not agree well with the measured results when using Ram 14 loading applied at one location (calculated/measured= 1.73).

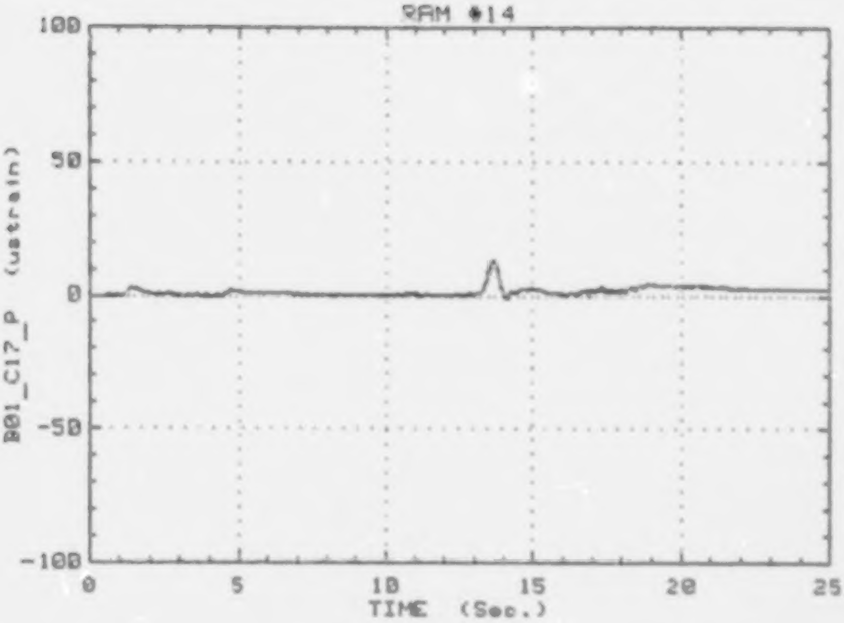
APPENDIX F

REPRESENTATIVE SAMPLES OF DATA AND CROSS REFERENCE TABLE

TABLE F1

SENSOR CROSS REFERENCE

Channel No.	Channel Identifier	Description
1	C_C24	Compression Gauge Stem Bar Cant Frame 24
2	C_C26	Compression Gauge Stem Bar Cant Frame 26
3	C_C28	Compression Gauge Stem Bar Cant Frame 28
4	C_C30	Compression Gauge Stem Bar Cant Frame 30
5	C_C32	Compression Gauge Stem Bar Cant Frame 32
6	C_C34	Compression Gauge Stem Bar Cant Frame 34
7	C_C36	Compression Gauge Stem Bar Cant Frame 36
8	C_C38	Compression Gauge Stem Bar Cant Frame 38
9	S_C27	Bending Gauge Stem Bar Cant Frame 27
10	S_C35	Bending Gauge Stem Bar Cant Frame 35
11	B3_C35C	Bending Gauge 3rd Deck Cant Frame 35 Centre Line
12	B3_C44C	Bending Gauge 3rd Deck Cant Frame 44 Centre Line
13	B2_C17C	Bending Gauge 2nd Deck Cant Frame 17 Centre Line
14	C_C20	Compression Gauge Stem Bar Cant Frame 20
15	C_C18	Compression Gauge Stem Bar Cant Frame 18
16	C_C16	Compression Gauge Stem Bar Cant Frame 16
17	C_C14	Compression Gauge Stem Bar Cant Frame 14
18	B01_C17_P	Bending Gauge 01 Deck Cant Frame 17 Port Side
19	B01_C27_P	Bending Gauge 01 Deck Cant Frame 27 Port Side
20	B01_C35_P	Bending Gauge 01 Deck Cant Frame 35 Port Side
21	B01_C44_P	Bending Gauge 01 Deck Cant Frame 44 Port Side
22	B01_39_P	Bending Gauge 01 Deck Frame 39 Port Side
23	B01_55_P	Bending Gauge 01 Deck Frame 55 Port Side
24	B01_86_P	Bending Gauge 01 Deck Frame 86 Port Side
25	B01_128_P	Bending Gauge 01 Deck Frame 128 Port Side
26	B3_39C	Bending Gauge 3rd Deck Frame 39 Centre Line
27	M_V	Ship Speed
28	M_A_T	Transverse Acceleration
29	M_A_L	Longitudinal Acceleration
30	M_A_V	Vertical Acceleration
31	C_C35_9P	Transverse Compression Gauge Port Side (Figure 6)
32	C_C35_10S	Transverse Compression Gauge Port Side (Figure 6)
33	C_C35_10P	Transverse Compression Gauge Port Side (Figure 6)
34	C_C35_11S	Transverse Compression Gauge Port Side (Figure 6)
35	C_C35_11P	Transverse Compression Gauge Port Side (Figure 6)
36	B01_C17_S	Bending Gauge 01 Deck Cant Frame 17 Stbd. Side
37	B01_C27_S	Bending Gauge 01 Deck Cant Frame 27 Stbd. Side
38	B01_C35_S	Bending Gauge 01 Deck Cant Frame 35 Stbd. Side
39	B01_C44_S	Bending Gauge 01 Deck Cant Frame 44 Stbd. Side
40	B01_39_S	Bending Gauge 01 Deck Frame 39 Stbd. Side
41	B01_55_S	Bending Gauge 01 Deck Frame 55 Stbd. Side
42	B01_86_S	Bending Gauge 01 Deck Frame 86 Stbd. Side
43	B01_128_S	Bending Gauge 01 Deck Frame 128 Stbd. Side
45	B3_55_P	Bending Gauge 3rd Deck Frame 55 Stbd. Side
46	B3_55_S	Bending Gauge 3rd Deck Frame 55 Stbd. Side
47	NULL	No Data
48	NULL	No Data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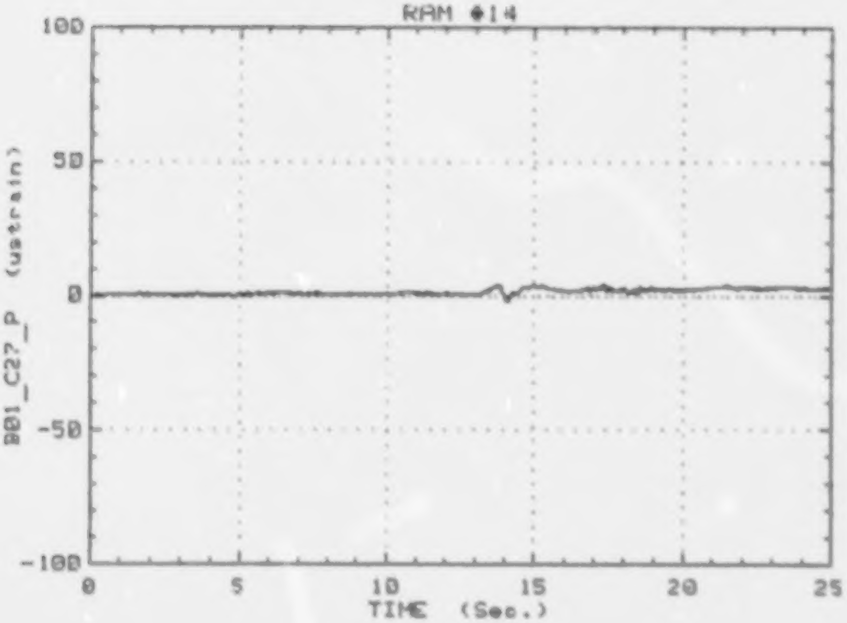
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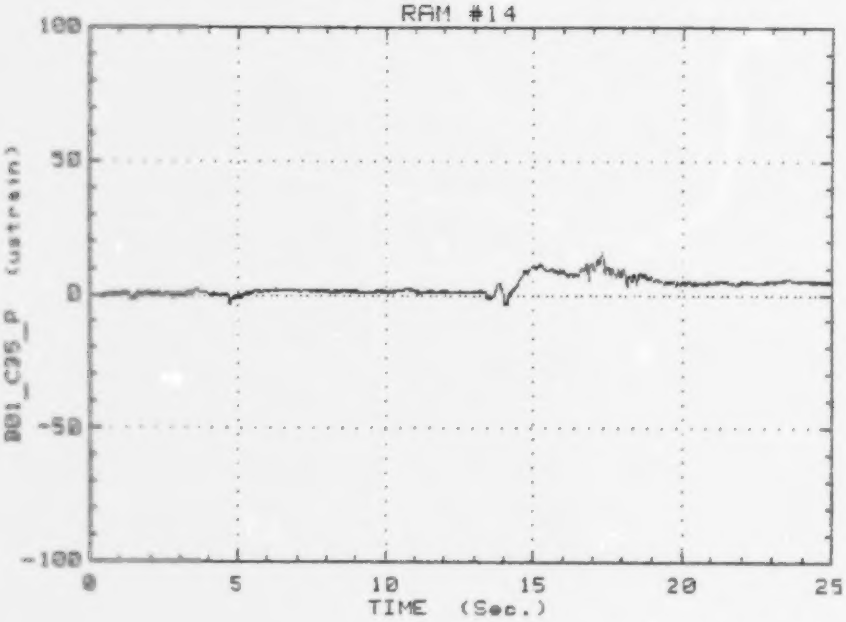
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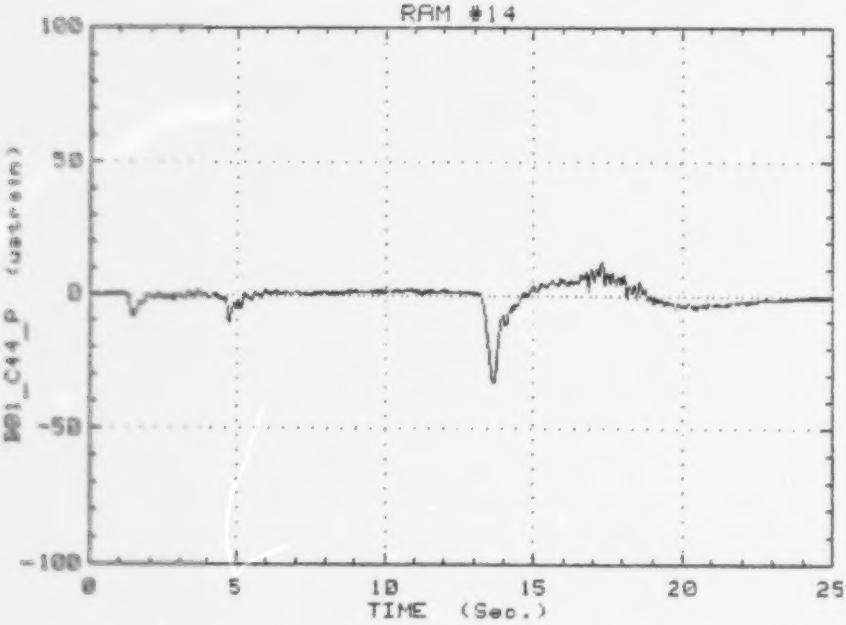
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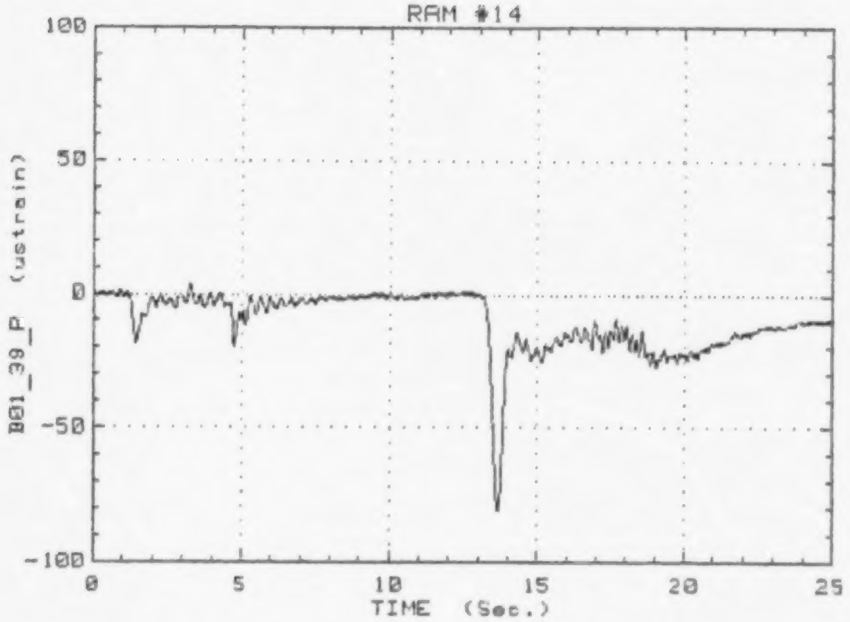
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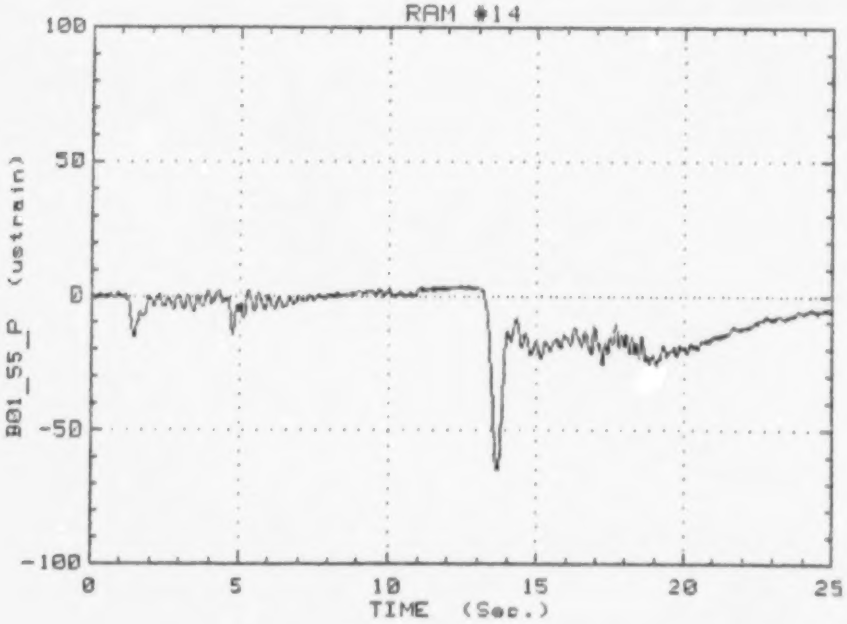
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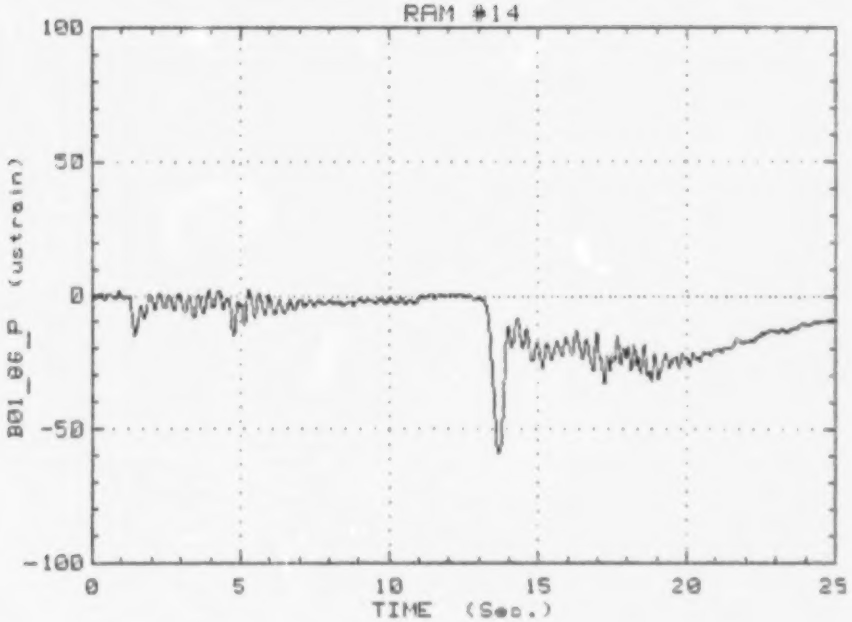
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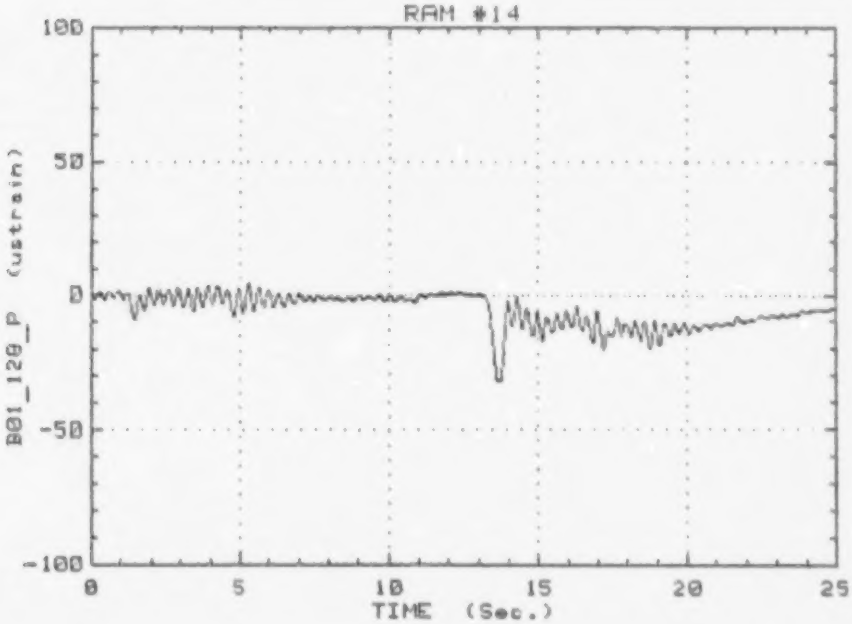
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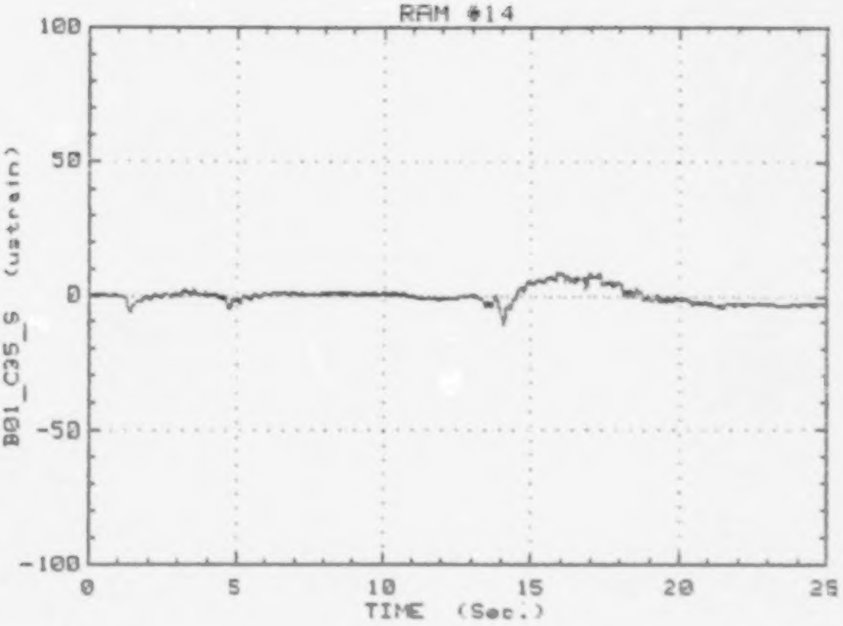
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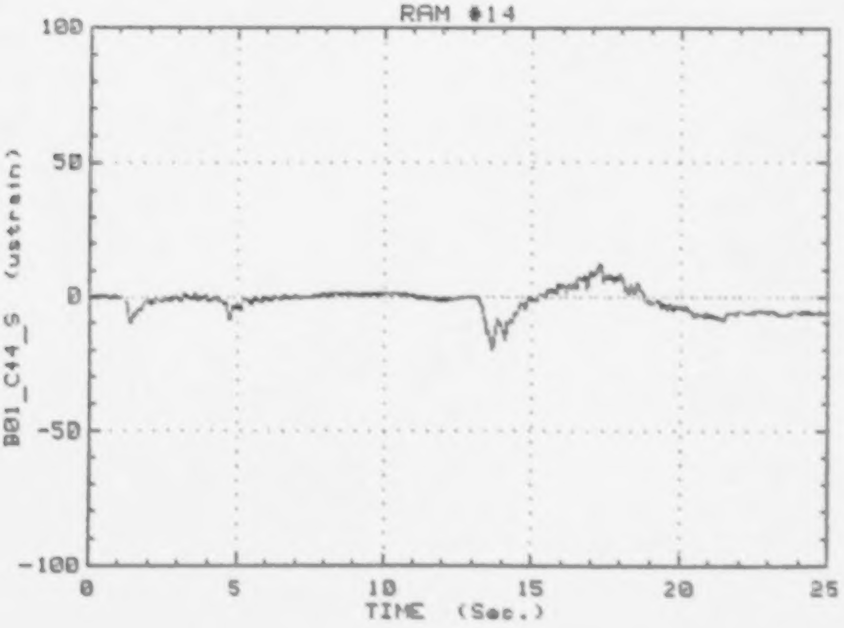
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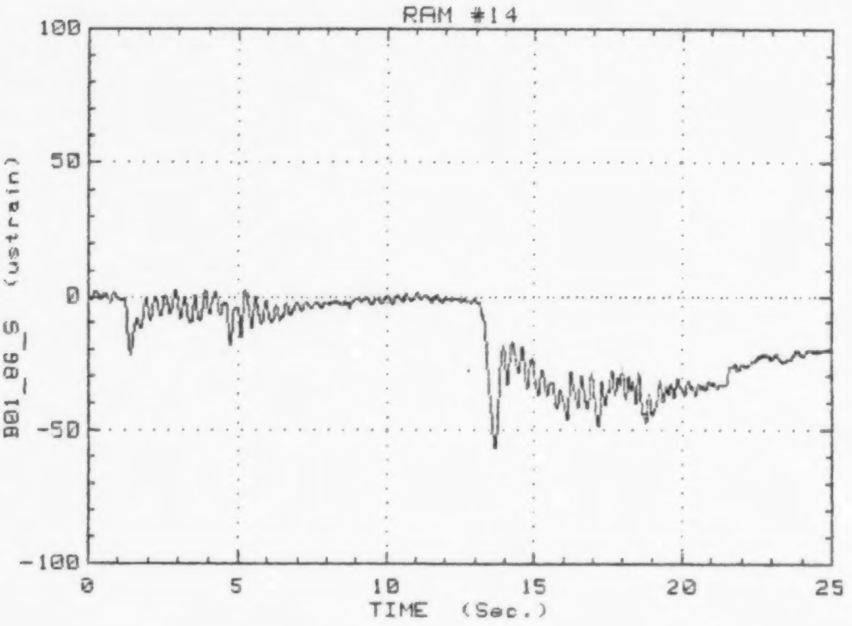
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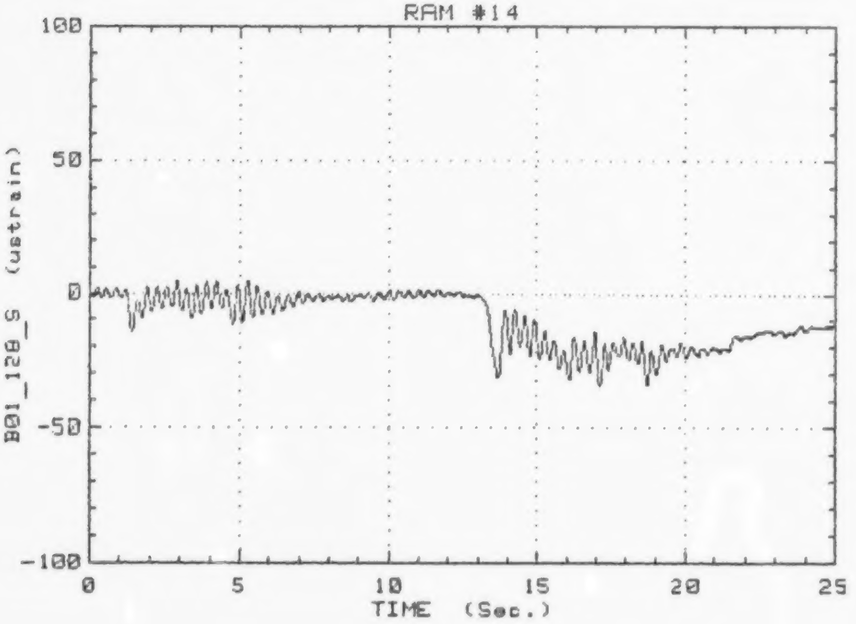
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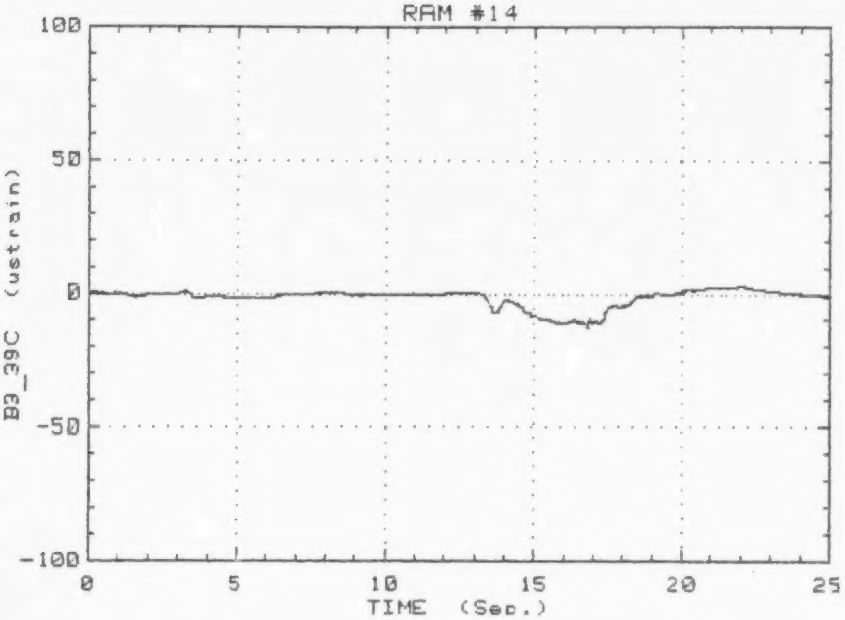

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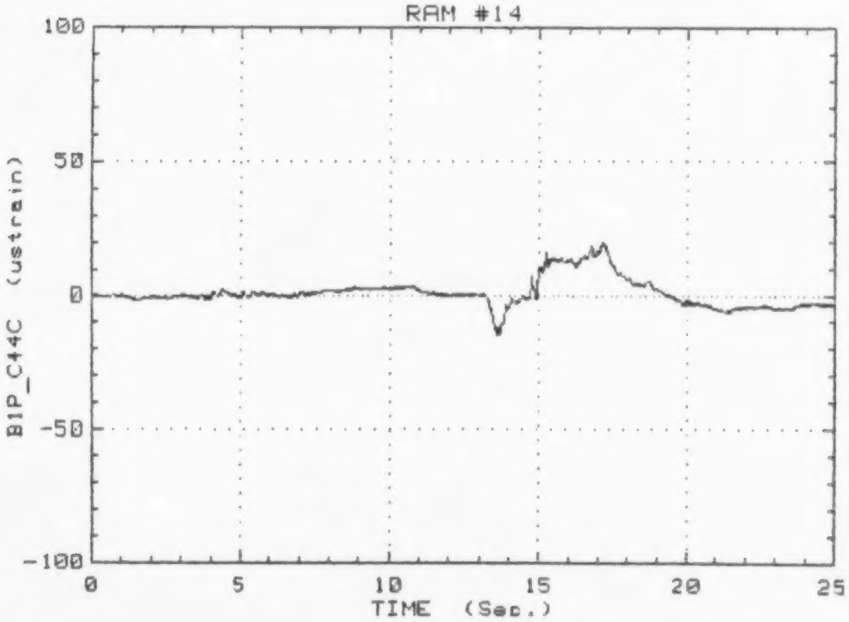

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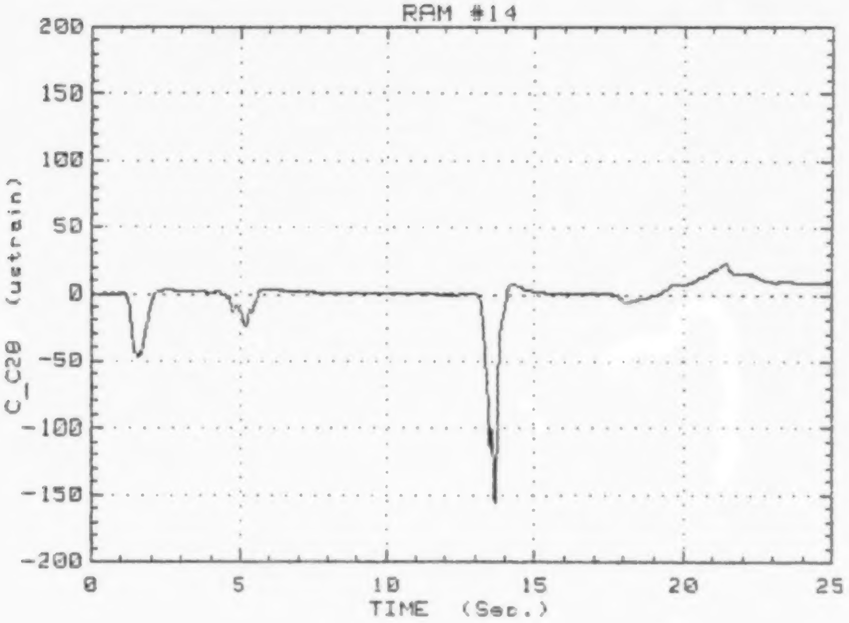
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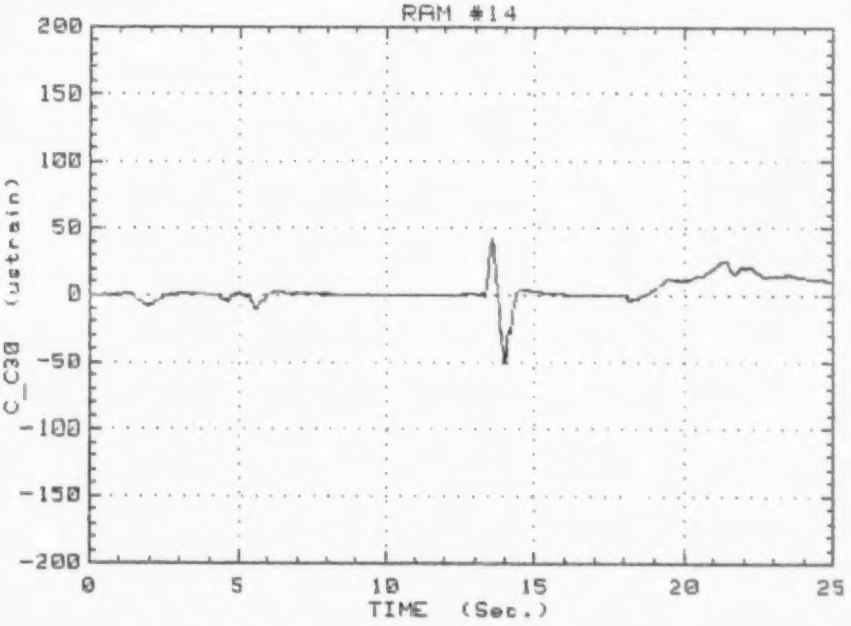
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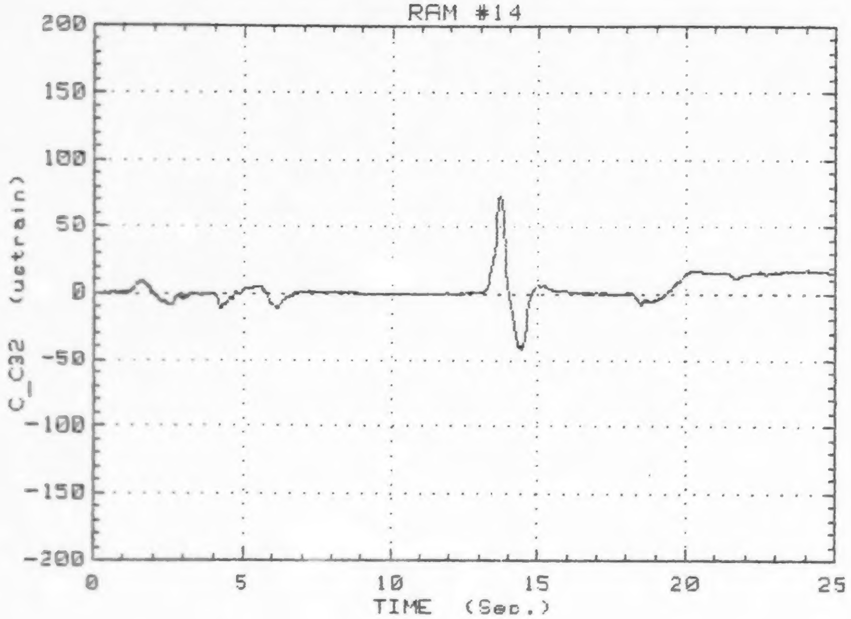

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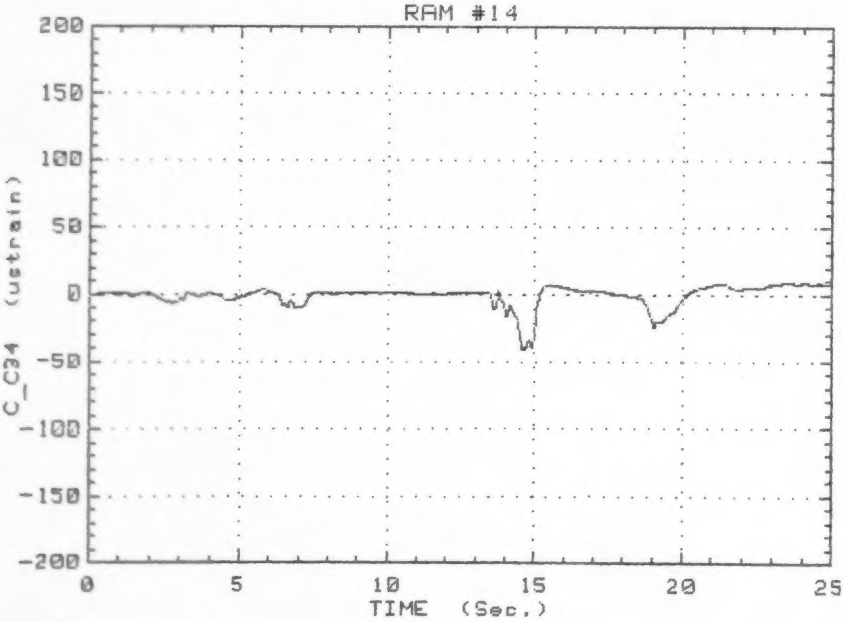

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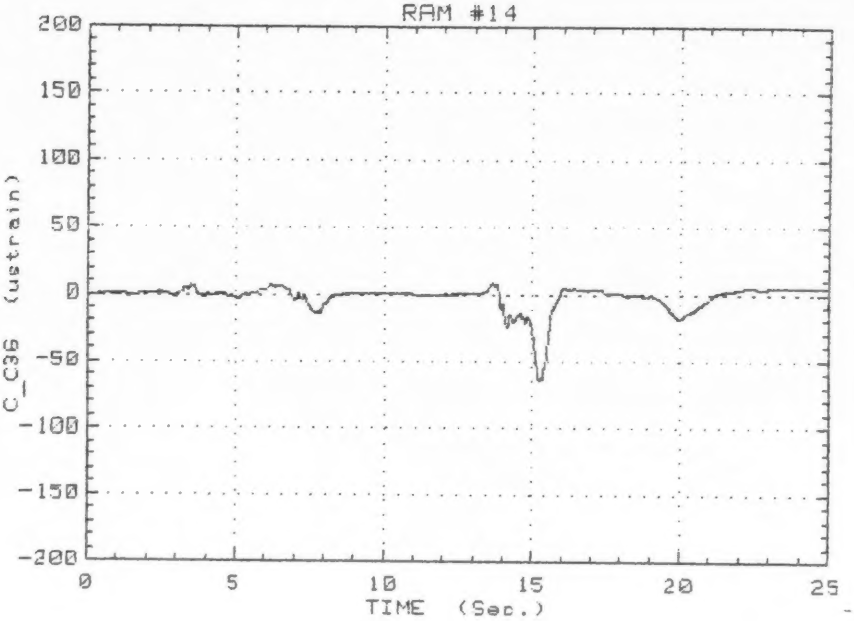
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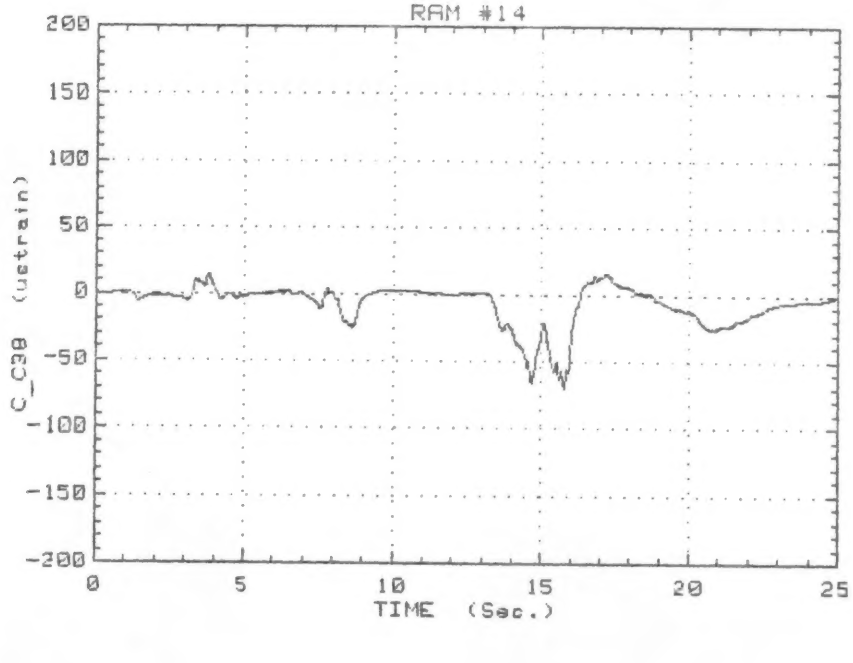
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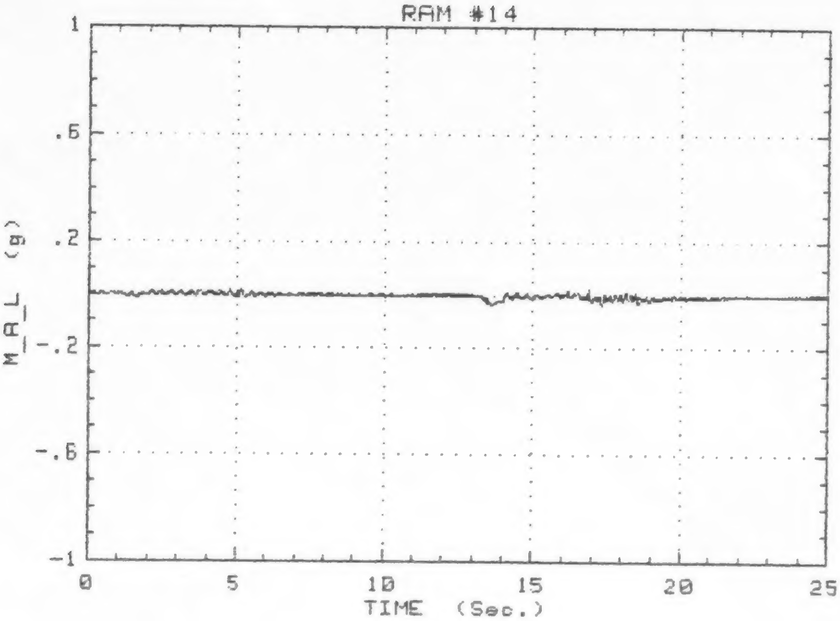
TIME (Sec.)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.2
-.2
-.6
-1
0
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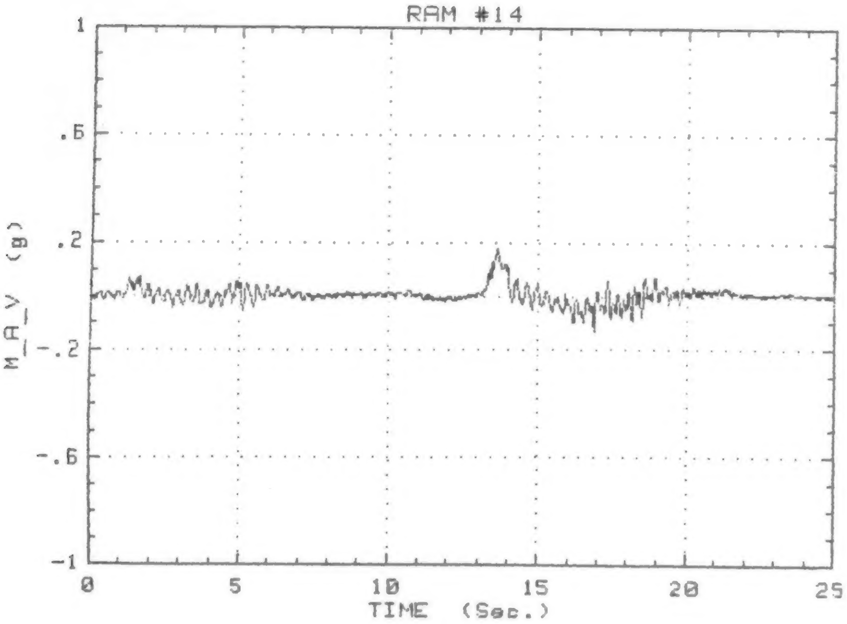
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0
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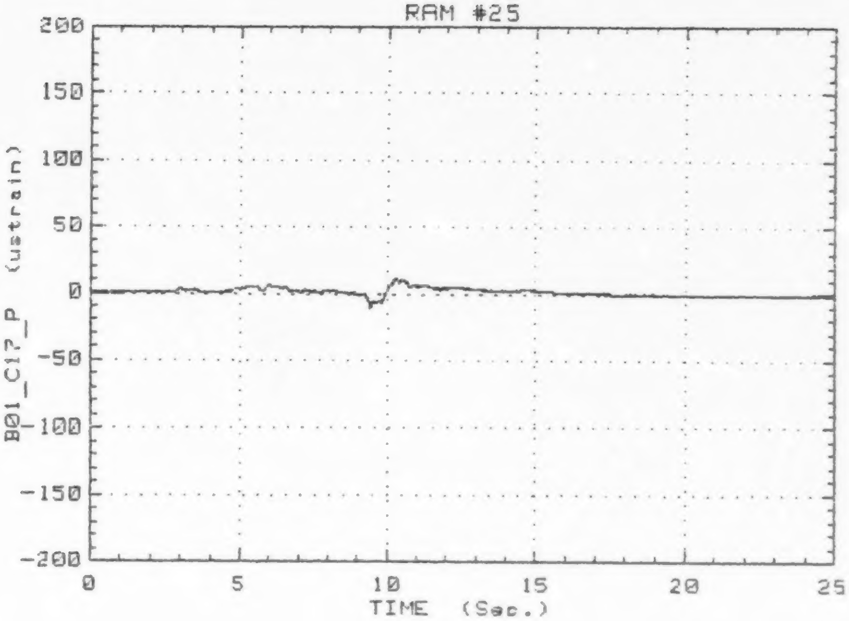
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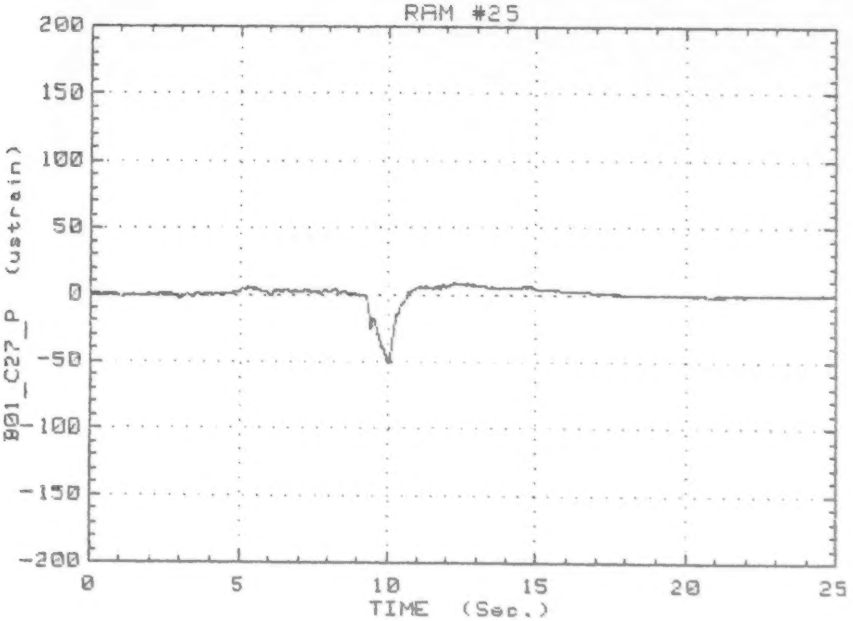
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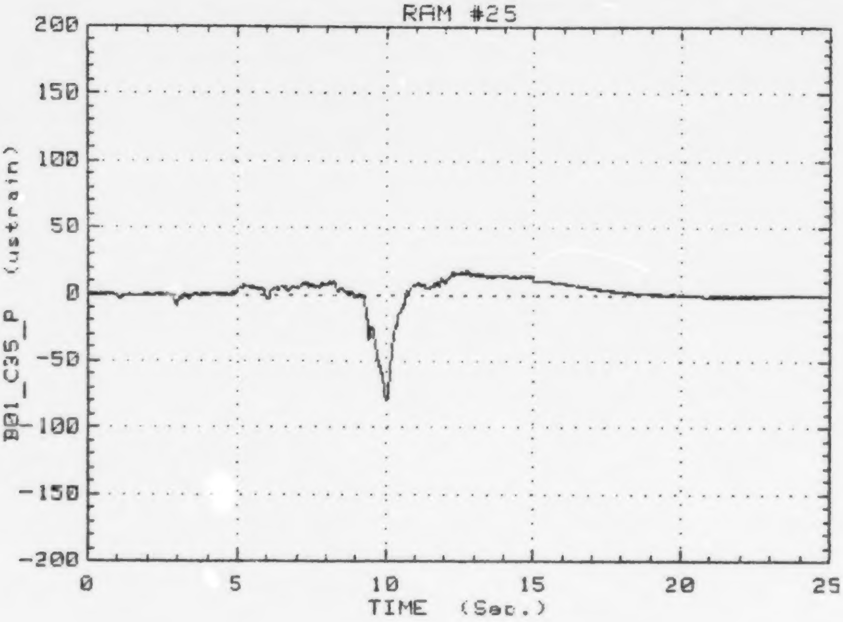
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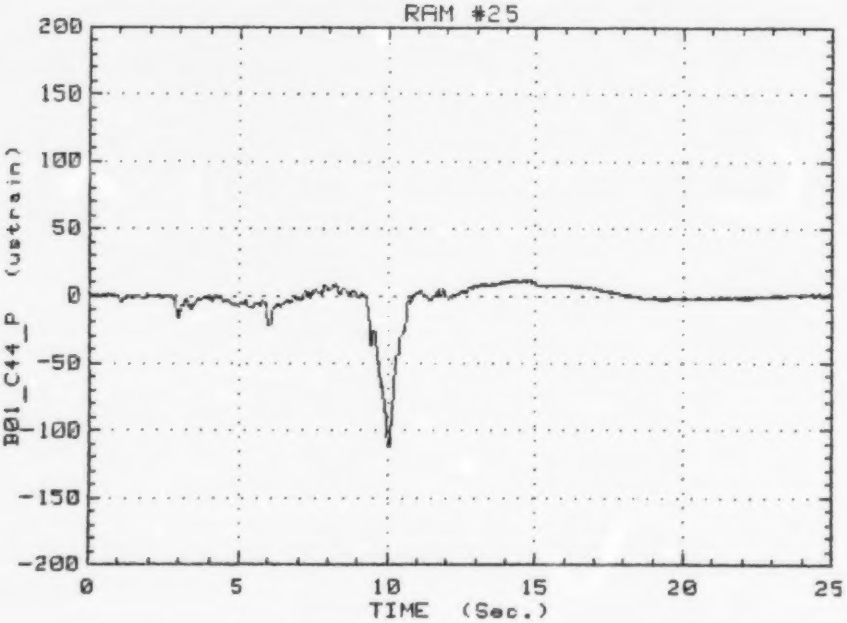
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15
20
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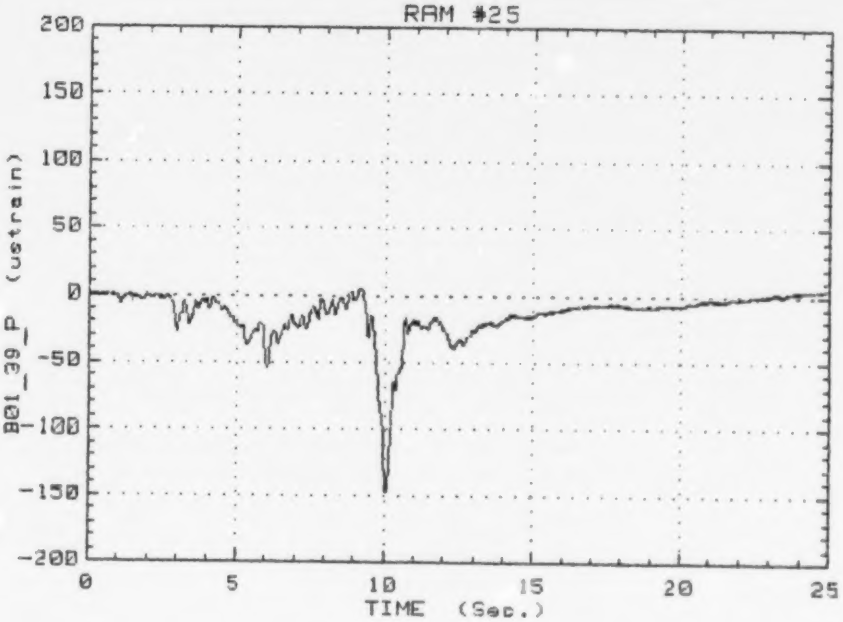
TIME (Sec.)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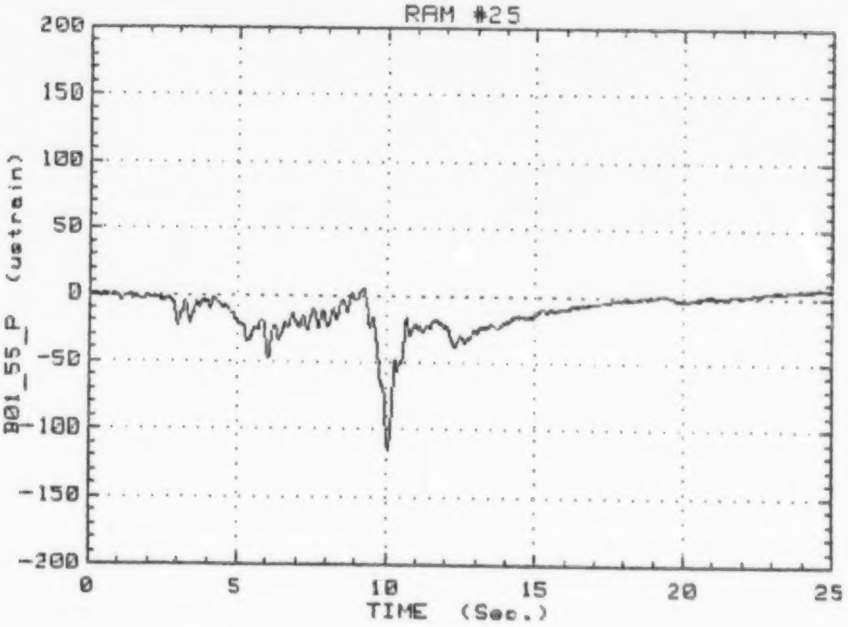
TIME (Sec.)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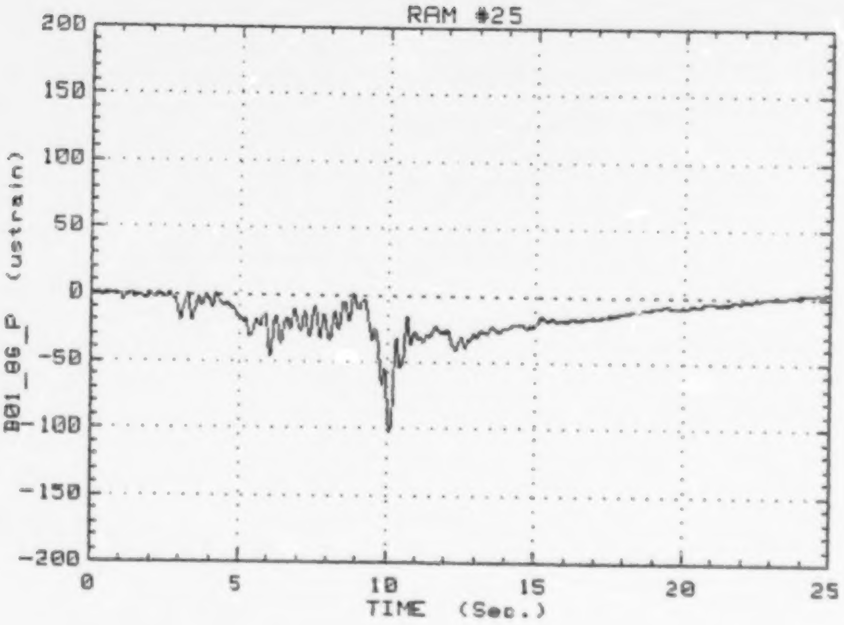
TIME (Sec.)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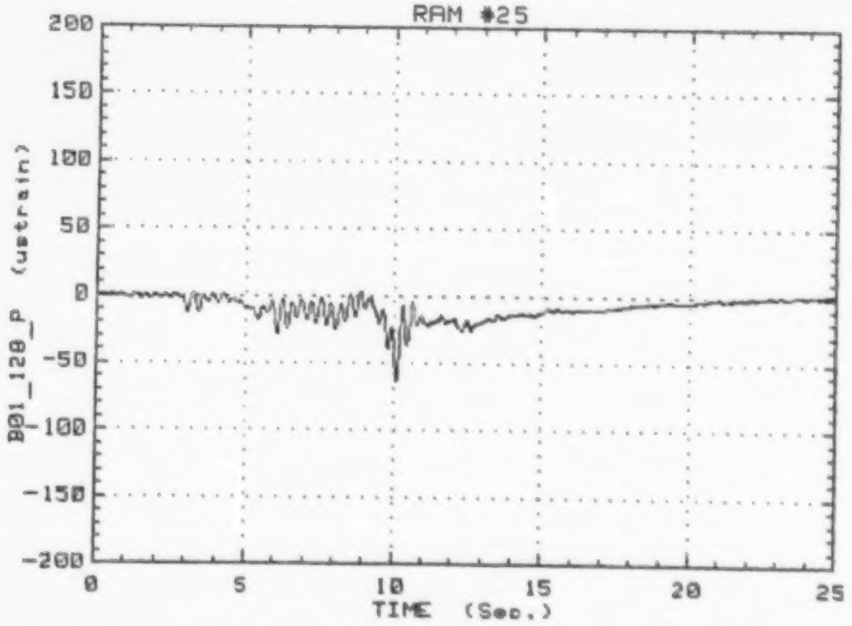
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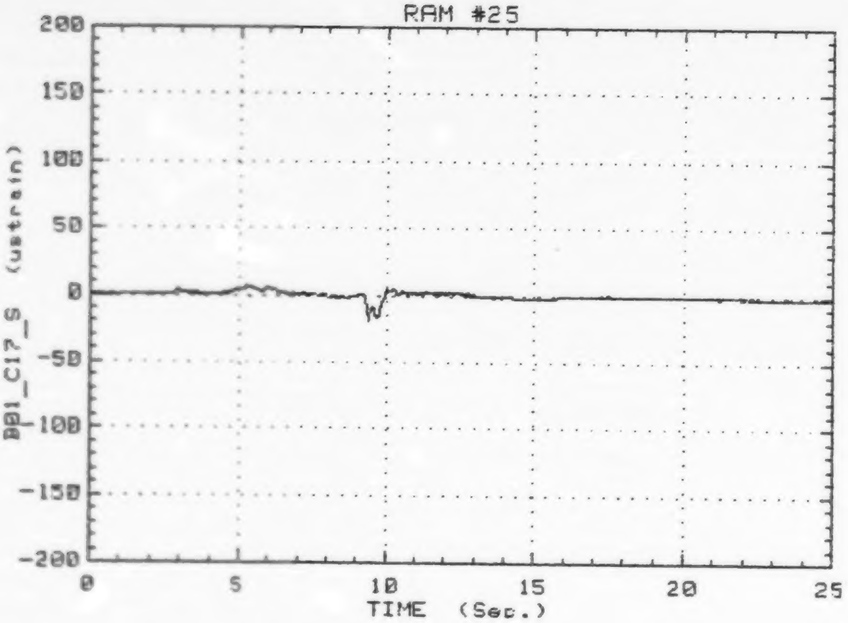
TIME (Sec.)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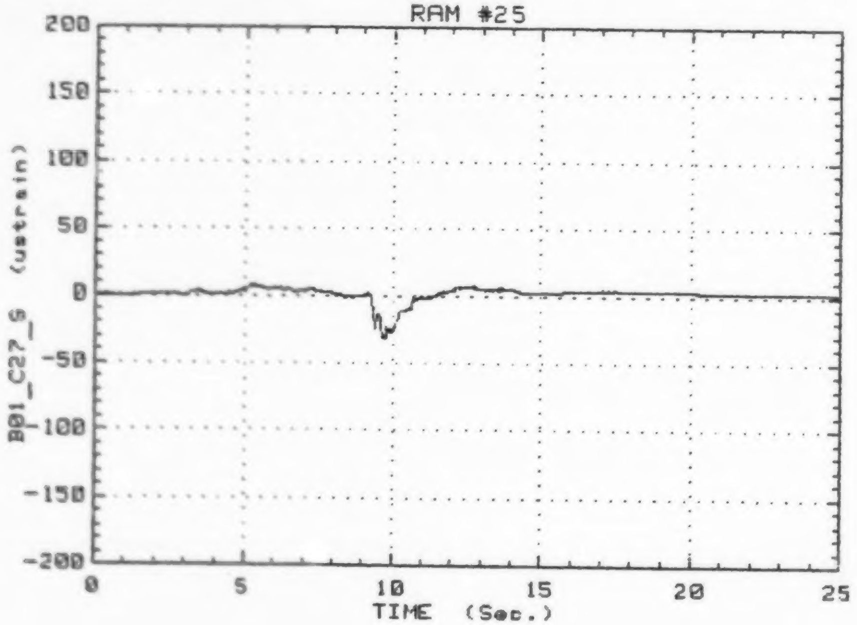
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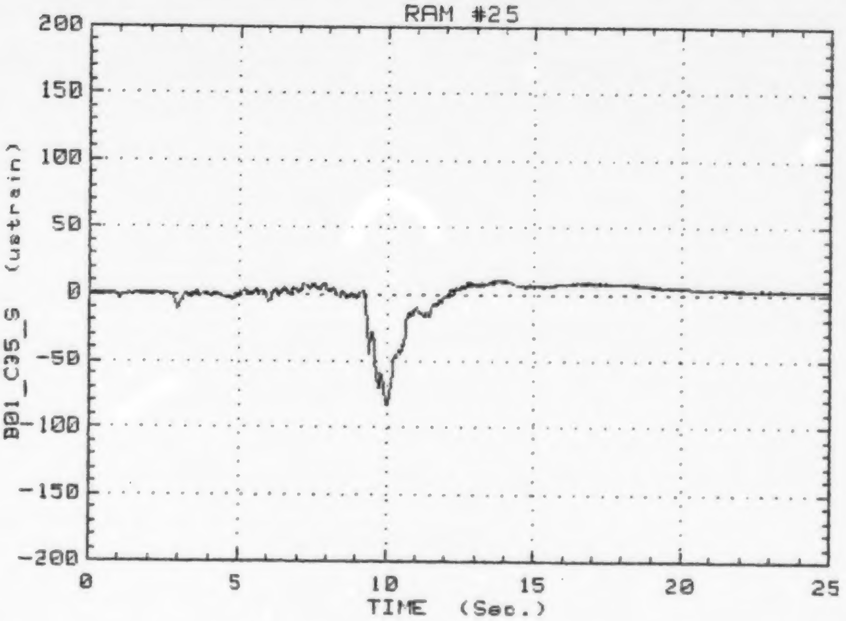
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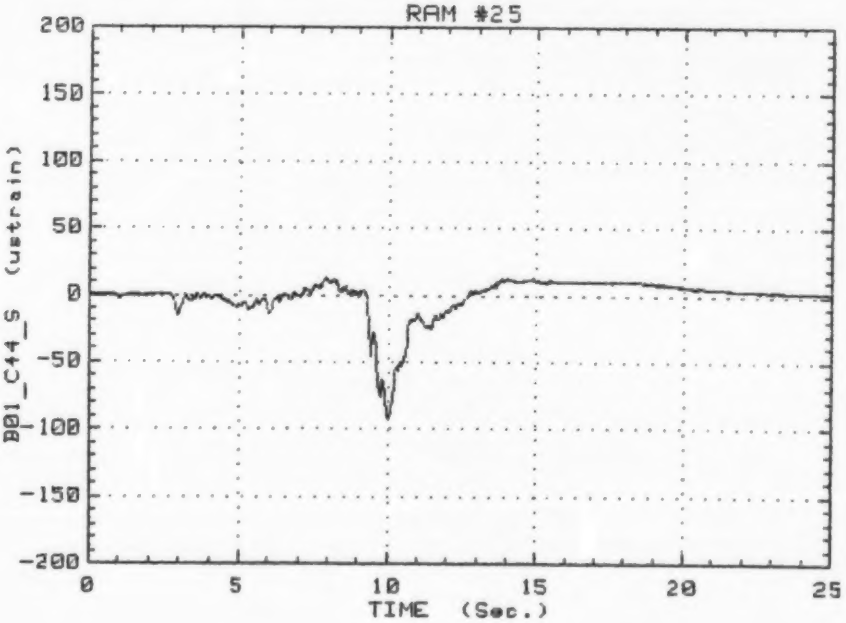
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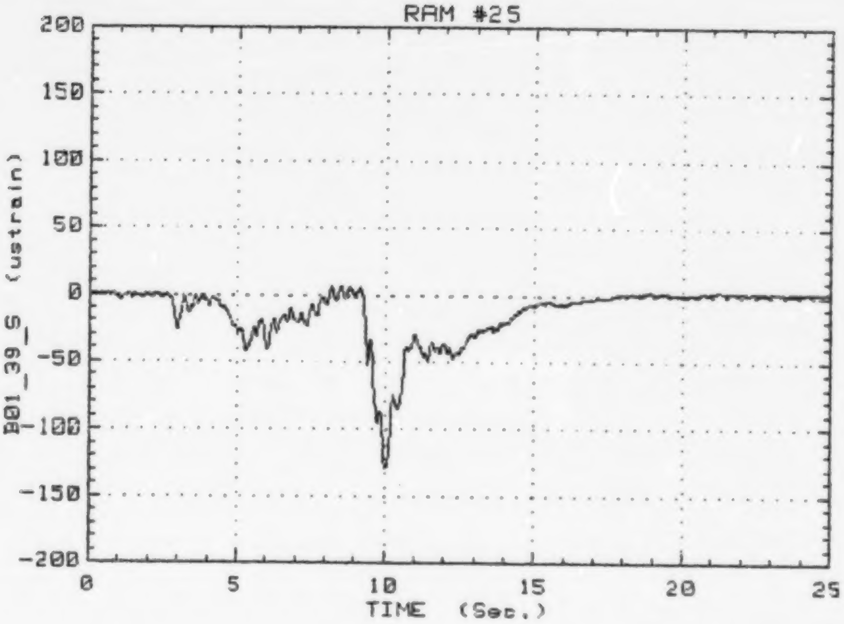
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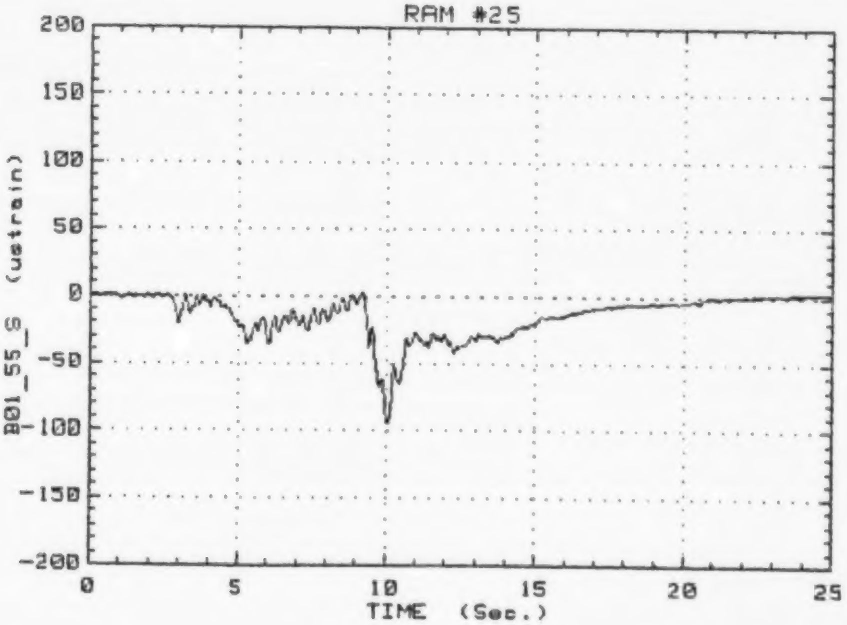
TIME (Sec.)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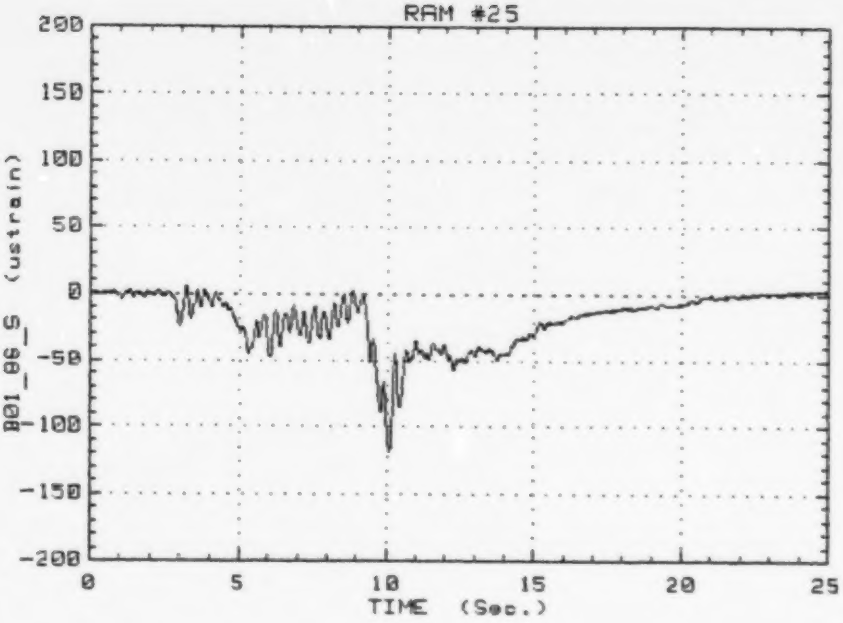
TIME (Sec.)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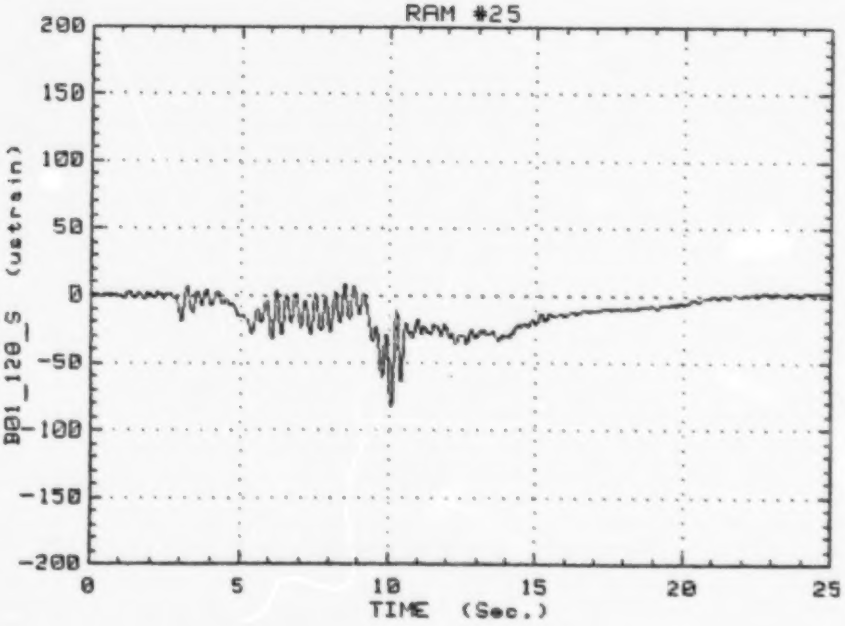
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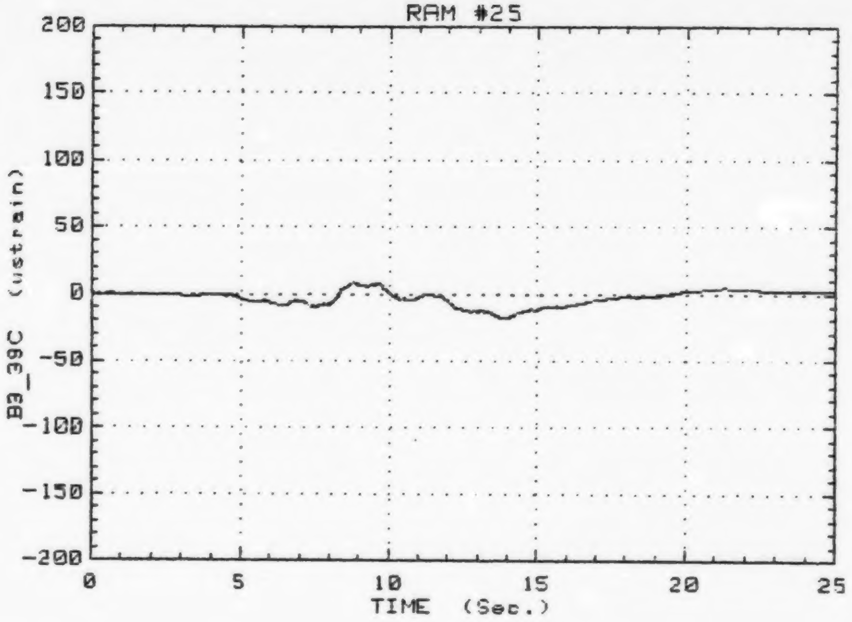
TIME (Sec.)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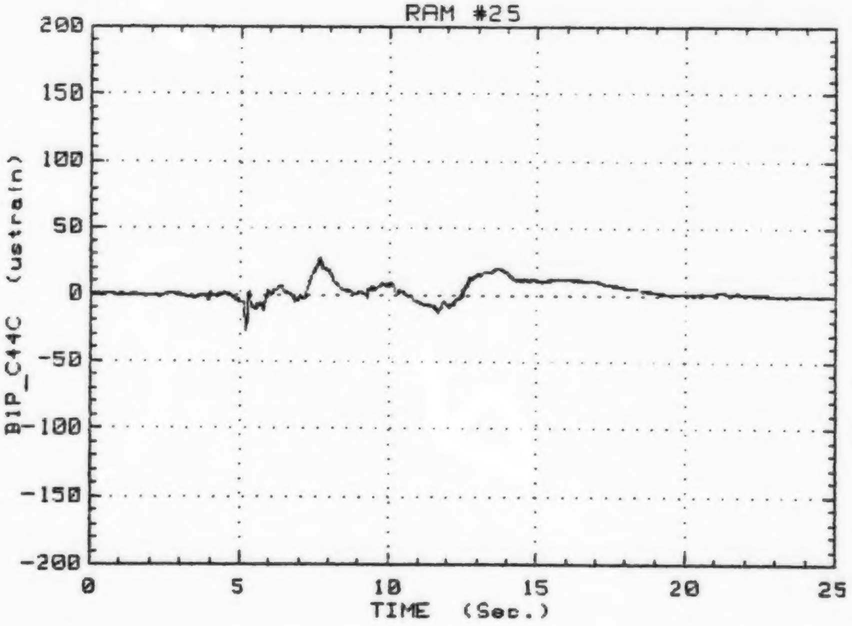
TIME (Sec.)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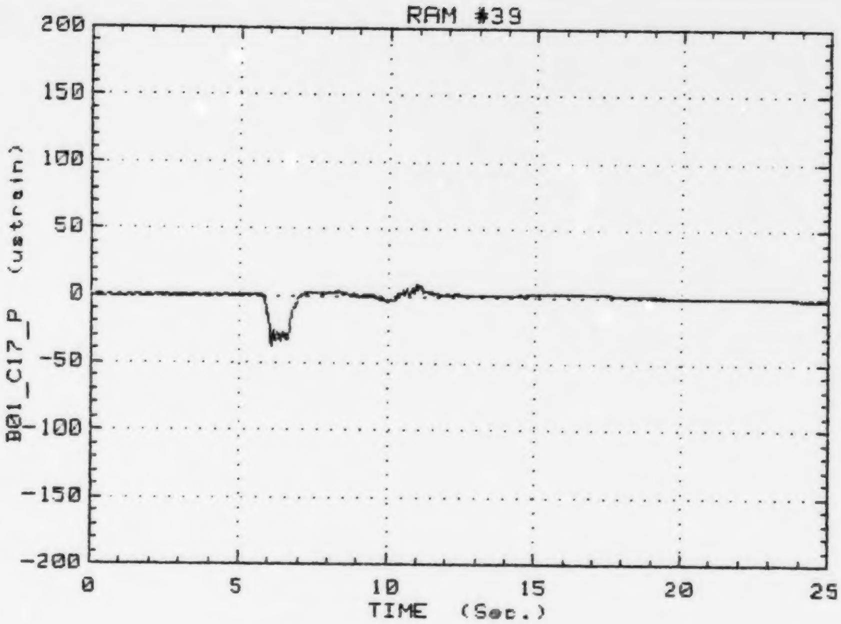
TIME (Sec.)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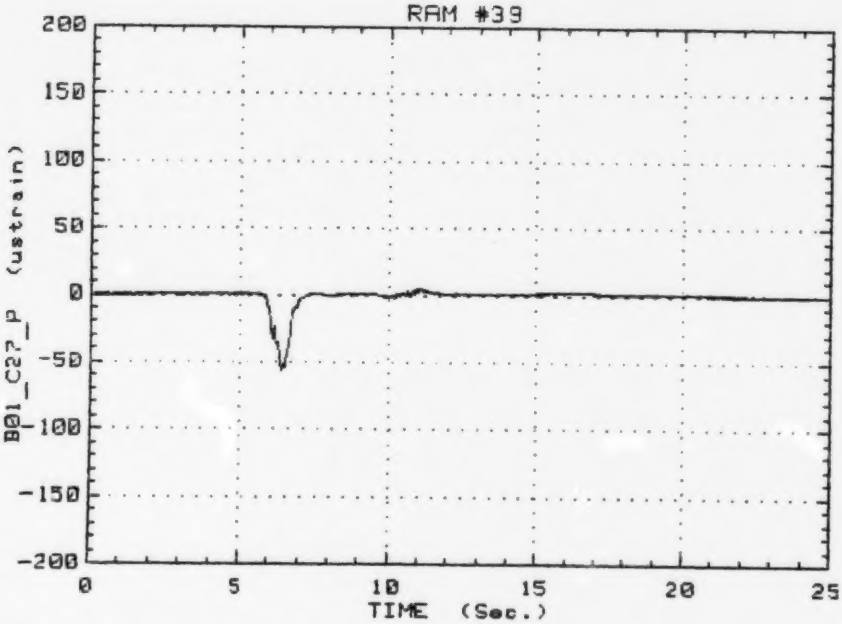
TIME (Sec.)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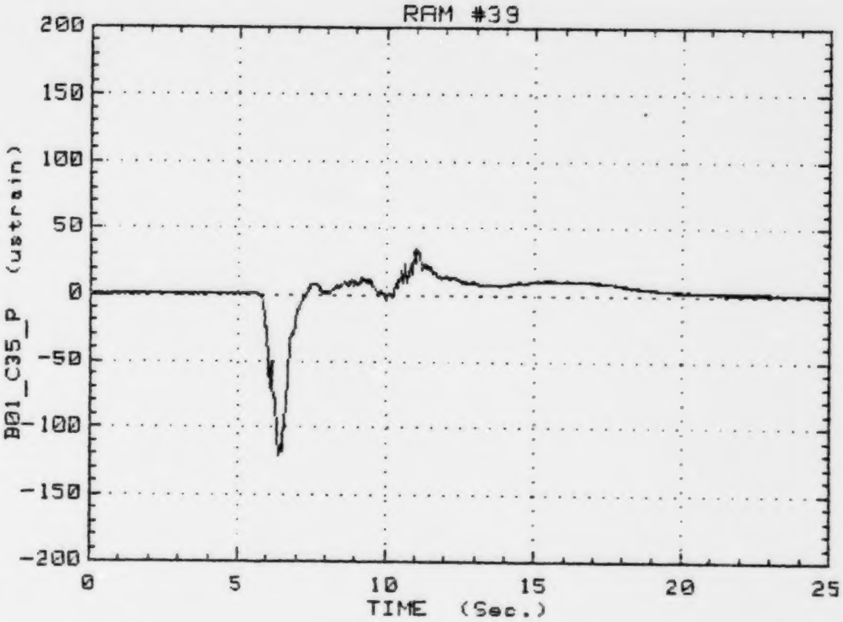
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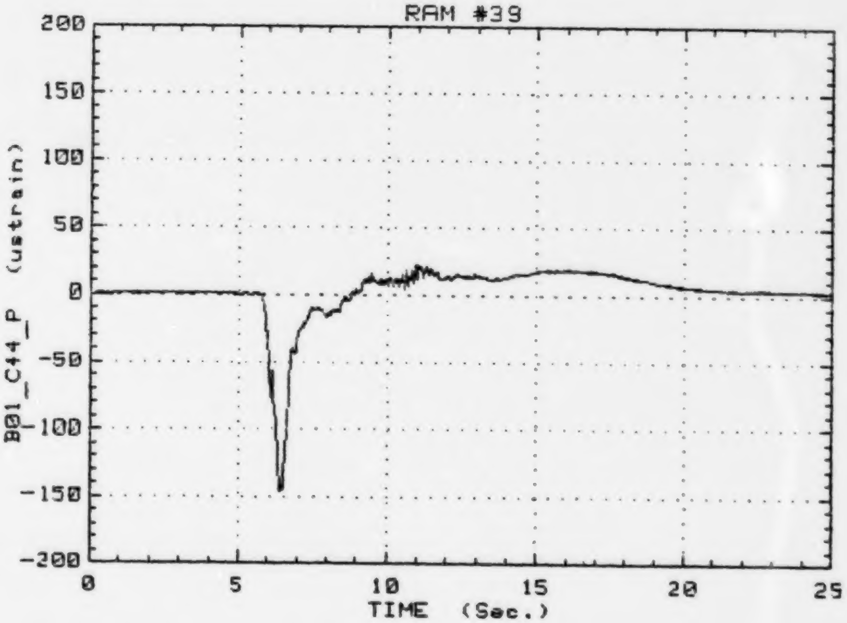
TIME (Sec.)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B01_C44_P (ustrain)
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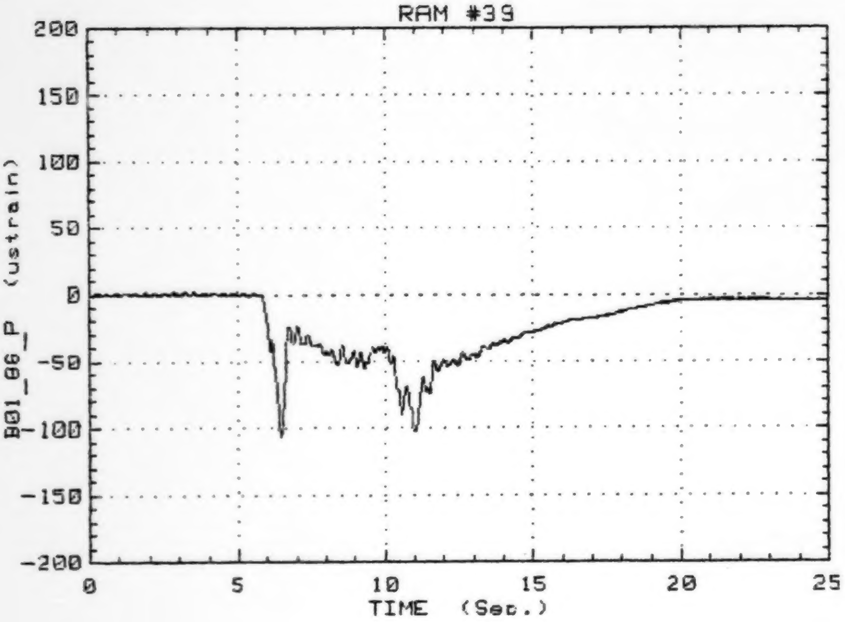
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B01_06_P (ustrain)
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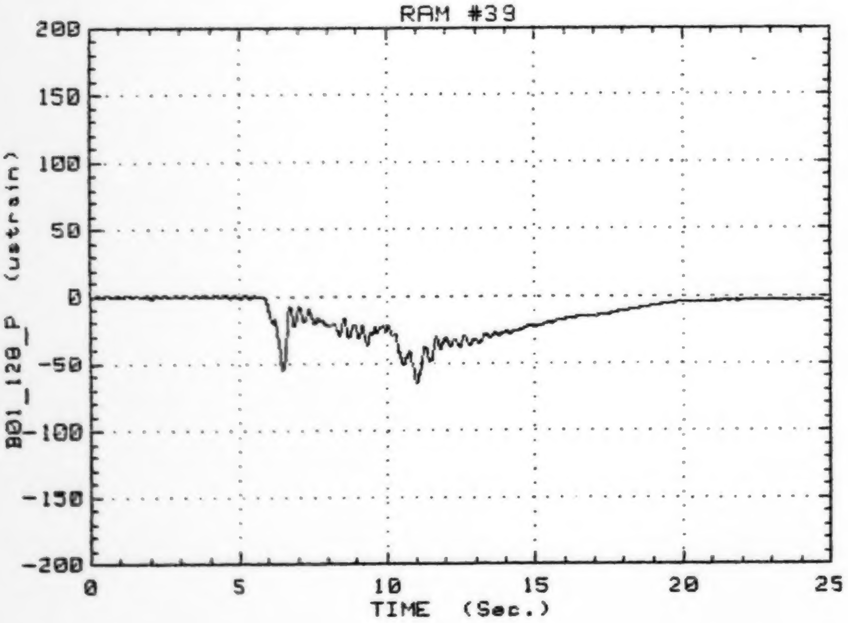
TIME (Sec.)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B01_120_P (ustrain)
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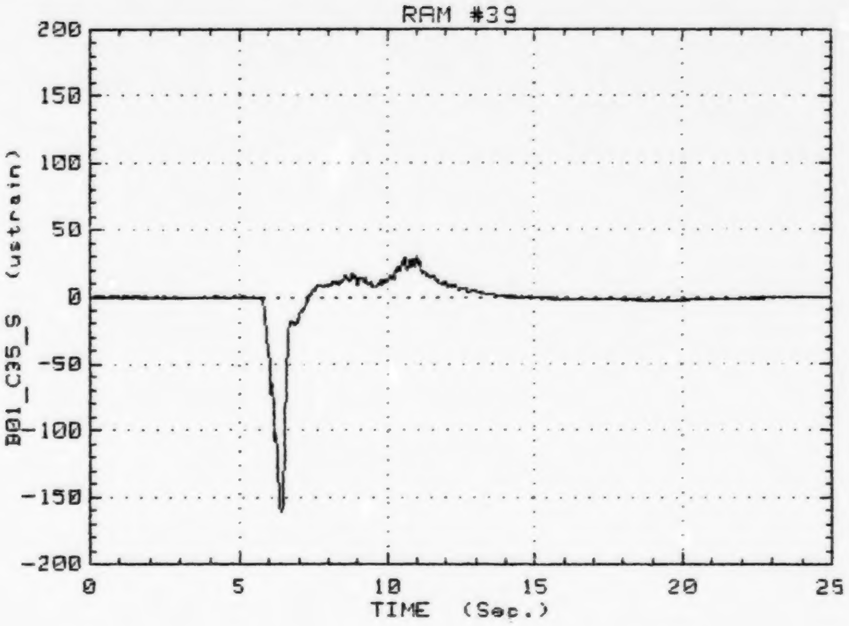
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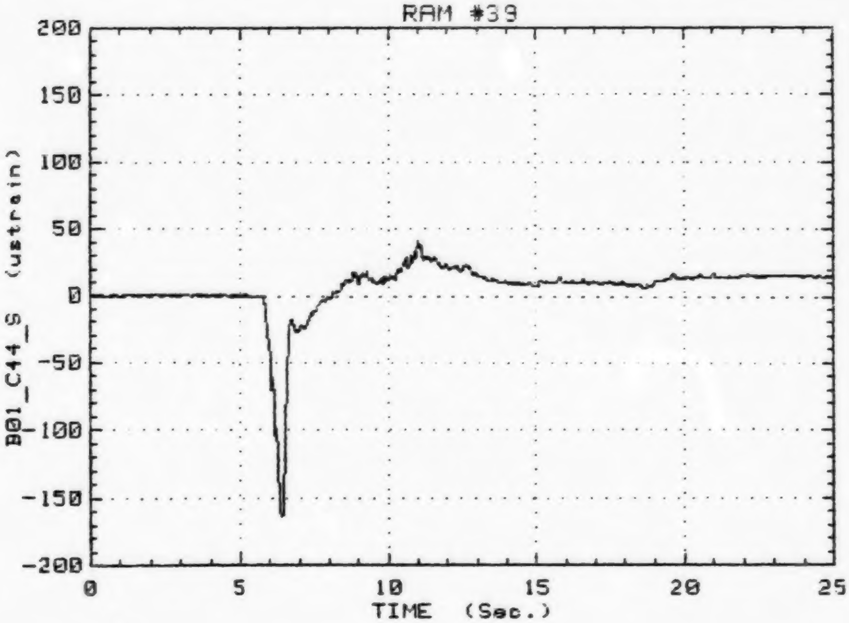
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B01_C44_S (ustrain)
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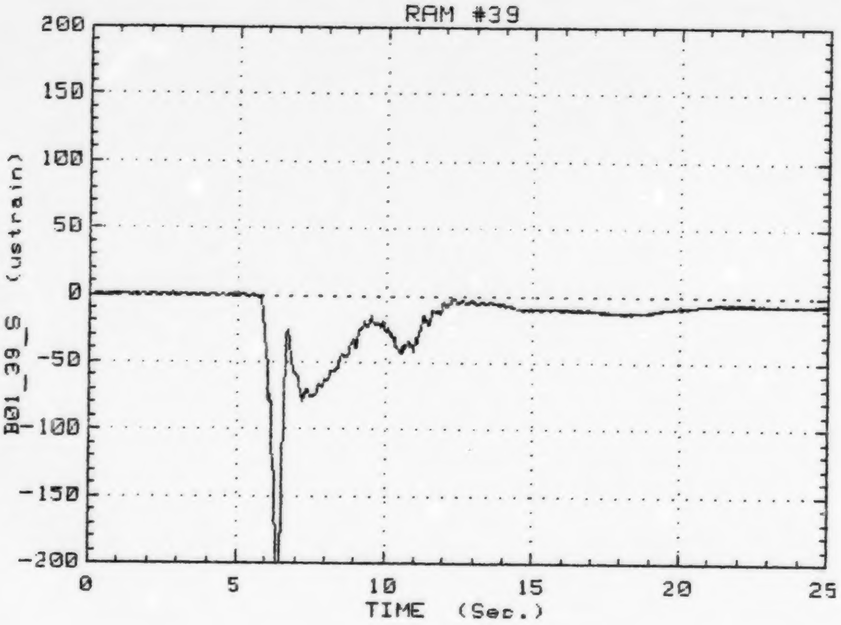
TIME (Sec.)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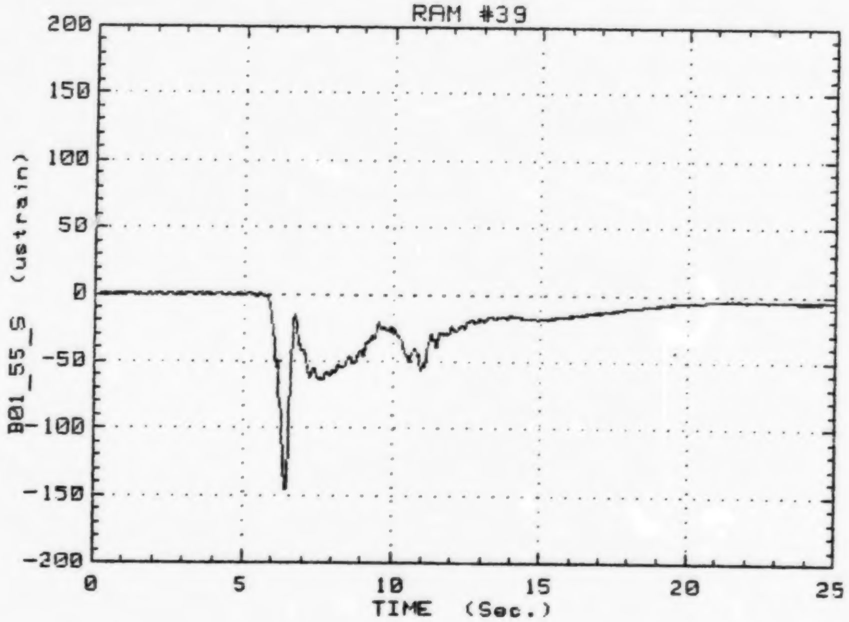
TIME (Sec.)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B01_55_S_ (ustrain)
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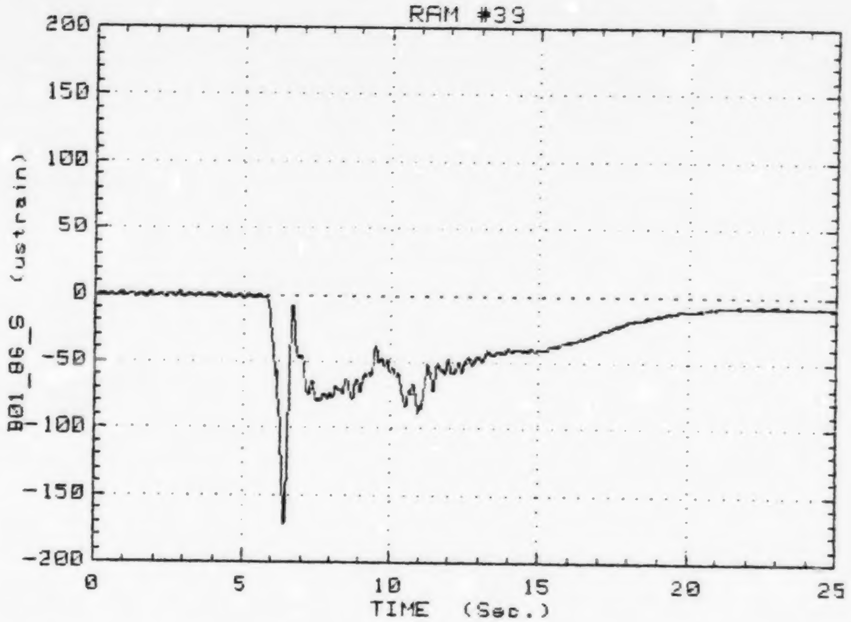
TIME (Sec.)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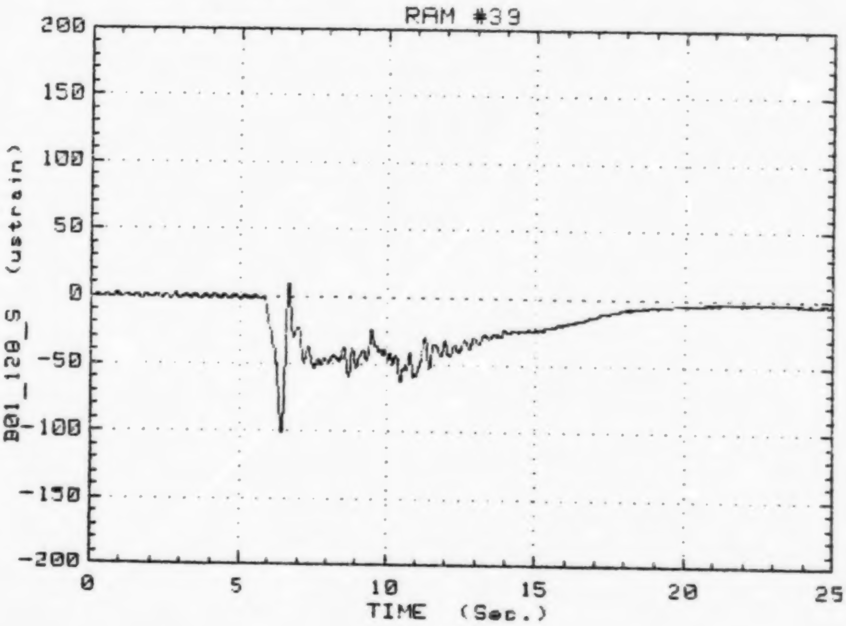
TIME (Sec.)


RAM #39
B01_120_S (ustrain)
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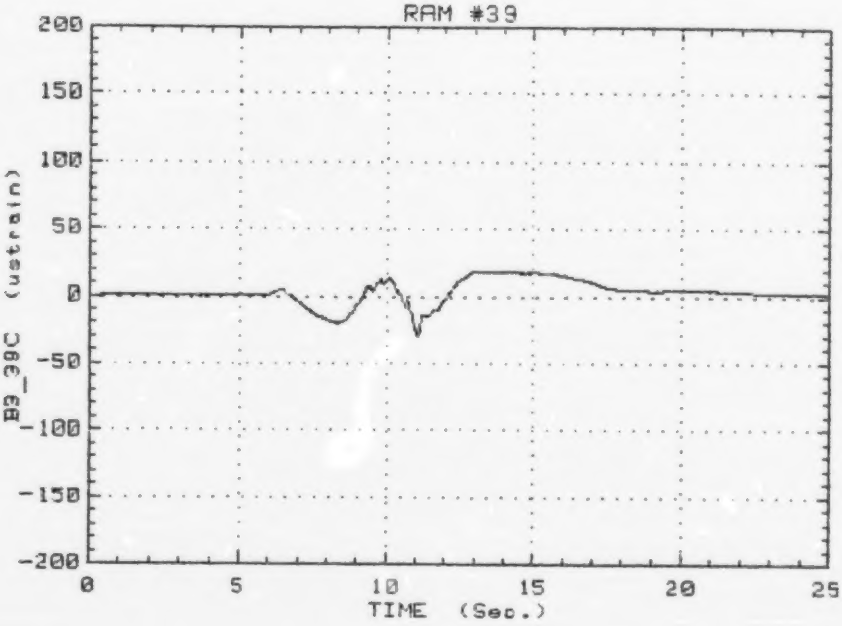
TIME (Sec.)


RAM #39
B3_39C (ustrain)
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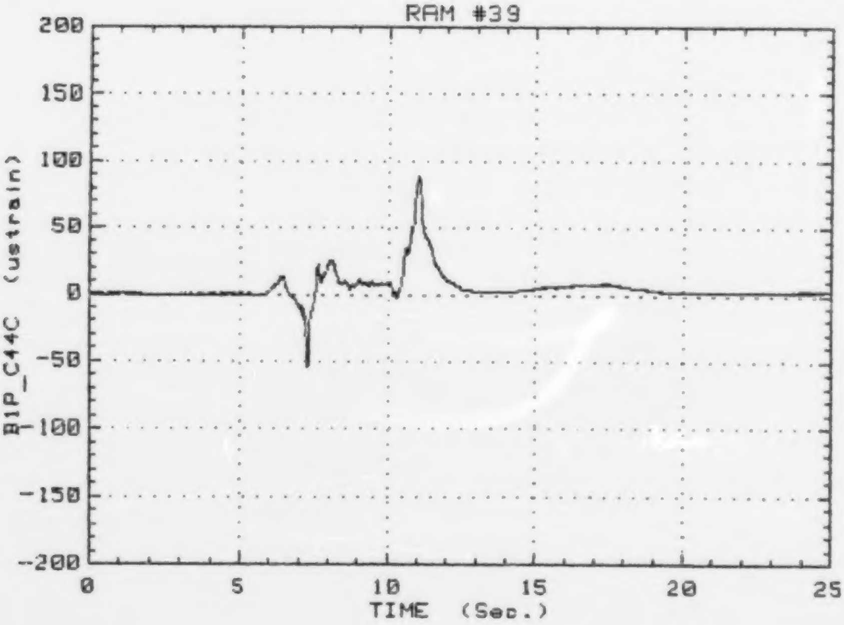
TIME (Sec.)


RAM #39
B1P_C44C (ustrain)
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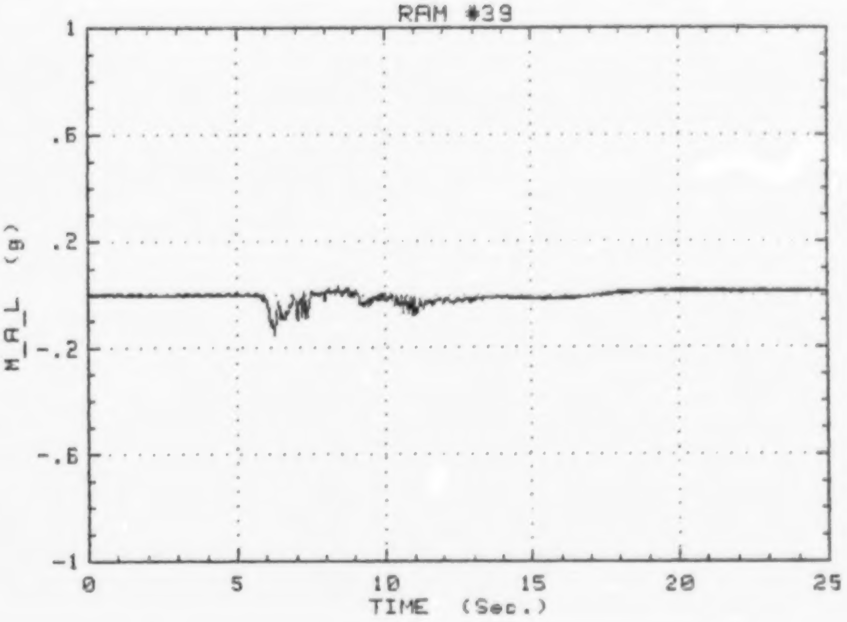
TIME (Sec.)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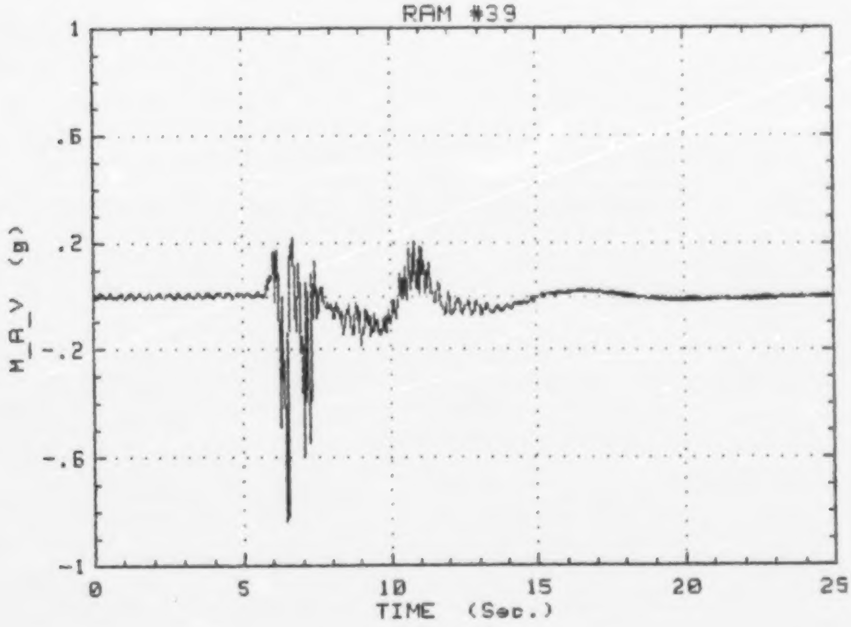
TIME (Sec.)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TIME (Sec.)